

Personal FM Systems in Children with a Spatial Processing Deficit

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ABSTRACT

Aims: The aims of this study were to identify school-aged children who exhibit spatial stream segregation deficits by using the Listening in Spatialized Noise – Sentences (LiSN-S) test, and to determine the effectiveness of personal FM systems as an intervention for these children.

Method: Participants consisted of 22 children between the age of 7;0 and 11;11 years with normal hearing thresholds. Based on their performance on the LiSN-S test, participants with normal and impaired spatial stream segregation ability were assigned to the control group (n=12) and the FM group (n=10) respectively. Participants from the latter group were provided with and required to use the personal ear-level FM devices during school time for a period of eight weeks. The impact of the FM systems was determined by both quantitative and qualitative data, which were gathered at three sampling points: (1) Before FM trial; (2) At the end of the FM trial (i.e. after eight weeks of use); and finally (3) At eight weeks following withdrawal of the FM systems.

Results: Results revealed children with APD improved on their ability to segregate spatial streams following the use of personal FM devices, whereas control participants did not exhibit this change. The personal FM devices seemed to provide the greatest benefit to the younger participants. Qualitative measures, including individualised Goal Attainment Scales (GAS), indicated positive improvements in auditory behaviours following the use of FM devices in all participants. In addition, teachers anecdotally reported positive behavioural changes in the FM participants during the FM trial.

Conclusion: Personal FM systems appear to be an effective management strategy for school age children who exhibit difficulty in spatial stream segregation.

ABBREVIATIONS

AEP	auditory evoked potential
AERP	auditory event-related potential
APD	auditory processing disorder
ASD	autistic spectrum disorder
C.H.A.P.S.	Children's Auditory Performance Scale
CNS	central nervous system
CTOPP	Comprehensive Test of Phonological Processing
Decibels	dB
FM	frequency modulated (system)
HVAC	heating, ventilation and air conditioning
LiSN-S test	Listening in Spatialized Noise-Sentence test
NEALE-3	Neale Analysis of Reading (3 rd Edition)
OME	otitis media with effusion
PA	phonological awareness
QUIL	Queensland University Inventory of Literacy
RM ANOVAs	repeated measures analysis of variance
SD	standard deviation
SLD	specific learning disability
SNR	signal-to-noise ratio
SPL	sound pressure level
SRT	speech recognition threshold

CHAPTER 1. LITERATURE REVIEW

1.1. *Introduction to the Problem*

The ability to listen to the teacher in the classroom is crucial for the academic development of all children in a mainstream school setting, where communication is primarily auditory-verbal in nature. It is estimated that 2 to 3% of school-aged children have poor listening skills resulting from neural dysfunction that cannot be readily explained by their peripheral hearing sensitivity (Chermak & Musiek, 1997). These children often exhibit poor *spatial stream segregation* abilities, experiencing significant difficulties separating a target signal from other competing signals. It is not surprising that many of these children complain of listening difficulties in the classroom, where the acoustics are often less than ideal. Indeed, the presence of multiple talkers and background noise in poor acoustic conditions makes many mainstream classrooms a challenging learning environment for children with normal hearing acuity and typically developing auditory processing skills - even more so for those with auditory processing disorder (APD).

One of the most effective strategies to improve signal-to-noise ratio (SNR) and make incoming signals more salient for children with APD is the use of personal frequency-modulated (FM) devices. Personal FM systems improve the SNR at the listener's ears by amplifying the speaker's voice via FM radio waves. Regardless of the distance between the child (i.e. listener) and the teacher (i.e. speaker) or the level of background noise and/or reverberation in the classroom, the resulting amplified signal is made clearer to the listener. It is proposed that the difference in loudness between the target signal and competing background signals enables the listener to differentiate the two signals as two distinct spatial streams (Cameron & Dillon, 2008). There is some evidence supporting the effectiveness of FM systems in individuals with suspected APD, particularly those who demonstrate difficulties in monaural low redundancy (MLR) speech tests and/or dichotic tests (Bellis, 2003; Johnston, John, Kreisman, Hall, & Crandell, 2009; Rosenberg, 2002; Smart, Purdy, & Kelly, 2010). However, the effectiveness of personal FM systems in children with identified spatial stream segregation deficits is yet to be reported.

The aims of this study were to identify school-aged children who exhibit spatial stream segregation difficulties by using the Listening in Spatialized Noise – Sentences (LiSN-S) test, and to determine the effectiveness of personal FM systems as an intervention for these children. Specifically, the impact of the FM systems was determined by both quantitative and qualitative data, which were gathered at three sampling points: (a) before the trial of FM systems; (b) at the end of an 8-week FM trial; and finally (c) at eight weeks following withdrawal of the FM systems.

1.2. Auditory Processing Disorder

Auditory processing refers to the neural processing of auditory stimuli in the central nervous system (CNS) (American Speech-Language-Hearing Association, 2005). Auditory processing disorder (APD), otherwise known as (central) auditory processing disorder ((C)APD; Jerger, 2000), is a condition wherein the processing of auditory information is impaired due to neural dysfunction, which is not attributable to intellectual impairment or peripheral hearing loss.

1.2.1. Prevalence of APD

Auditory processing disorder has been described in adults (e.g. Musiek, Baran, & Shinn, 2004) and children (e.g. Chermak, 2002; Oberklaid, Harris, & Keir, 1989; Sahli, 2009). The prevalence of APD has not yet been formally established, which reflects the lack of consensus regarding the current criteria for assessment and diagnosis of APD. Nonetheless, it is estimated that 23% of older adults (Cooper & Gates, 1991) and 70% of adults over the age of 60 in the clinical population have some form of APD (Cooper & Gates, 1991; Stach, Spretnajak, & Jerger, 1990). In the paediatric population, the estimated prevalence rate of APD is approximately 2 to 3%, with a two to one ratio of boys to girls (Chermak & Musiek, 1997).

1.2.2. Aetiology of APD

While the aetiology of APD remains largely unknown, studies have demonstrated that APD may be attributed to abnormal neuromorphological changes or dysfunction of neurological structures. Previous studies have suggested that abnormal neuromorphology and neurological disorders (including trauma to neurological structures and other neurodegenerative diseases)

accounts for up to 5% (Musiek, Baran, & Pinheiro, 1992) and 70% (Chermak & Musiek, 1997) of paediatric and adult suspected APD cases respectively. The remaining paediatric cases are thought to result from delayed maturation of the central auditory nervous system (Musiek, Kibbe, & Baran, 1984). Such a delay may be directly related to a more common and detectable putative cause of APD in children, namely a history of chronic otitis media with effusion (OME) (Moore, Hartley, & Hogan, 2003).

Otitis media with effusion is the most common cause of hearing impairment in children. In a retrospective study based in the UK, history of chronic OME was reported in 29% of APD children ($n = 17$) as opposed to 10% of children without APD ($n=38$) (Dawes, Bishop, Sirimanna, & Bamiou, 2008). In New Zealand, OME affects approximately 18% of five year olds (Silva & R., 1996; Stewart & Silva, 1996). More recently, amongst the 5.6% of three year olds who failed on tympanometry in the national screening programme (National Audiology Centre, 2000), Pacific Island and Maori children were found to have the highest failure rate of 10.5% and 11.1% respectively (National Audiology Centre, 2000). Similarly, of the 7.7% of school entrants who failed the screening programme, 13.9% and 13.8% were of Pacific Island and Maori descent respectively.

Chronic OME reduces the intensity and delays the transmission of an incoming signal from the middle ear to the brain. This often results in asymmetrical hearing between the right and left ears, which presumably leads to abnormal development of binaural processing (Hartley & Moore, 2003). Binaural processing can significantly improve speech understanding in background noise through a phenomenon known as binaural squelch - a centrally mediated segregation of a signal from noise when that signal and noise are at different locations producing temporal and intensity differences at the two ears (Gray, Kesser, & Cole, 2009; Hall, Grose, Dev, & Ghiassi, 1998; Moore, Hutchings, & Meyer, 1991). Binaural processing is therefore particularly important for speech discrimination in noisy environments, and its development is reliant upon both ears receiving accurate and balanced transmission of acoustic signals (Roberts et al., 2004).

Studies of auditory processing in animals (Hartley & Moore, 2003; Hogan & Moore, 2003; Knudsen, 2002; Moore et al., 1999), children (Hall, et al., 1998; Moore, et al., 2003; Moore, et al., 1991) and adults (Hall & Grose, 1993) have consistently demonstrated that

conductive hearing loss not only attenuates sound, but also increases transmission time through the middle ear. These changes distort the important acoustic cues required for binaural hearing, including reduced binaural squelch, and abnormal interaural level differences (ILDs) and interaural time differences (ITDs) (Gray, et al., 2009; Knudsen, 2002), which are not immediately improved even with restoration of normal binaural hearing. Fortunately, once consistent auditory input has been restored, a gradual recovery of binaural function is generally evident (Moore, et al., 2003; Moore, et al., 1999), such that children appear to recover good binaural hearing by late childhood. However, this recovery can take several years (Hogan & Moore, 2003; Moore, et al., 2003) and throughout this time, a child's ability to discriminate speech in noisy environments - such as the classroom - may be significantly impaired (Zumach et al., 2009). Thus, just as the consequences of chronic conductive hearing loss can outlive the actual disease itself by years, the functional consequences of binaural processing deficits may have significant long-term effects on a child's learning and academic achievement.

Temporal processing difficulties, as seen in normal hearing children with dyslexia and/or learning disabilities, have also been demonstrated to affect speech perception in noise (Anderson, Skoe, Chandrasekaran, & Kraus, 2010). In auditory perception, temporal cues are not only important for localization, but also in the formation of *auditory objects* (Shinn-Cunningham & Best, 2008). An auditory object is loosely defined as "a perceptual entity that is perceived as coming from one physical source" (Shinn-Cunningham, 2008b), where objects with similar high-order perceptual features – such as location and pitch – are grouped together over time to form a stream (Darwin & Carlyon, 1995). However, the process of object formation is adversely affected when the auditory signal is degraded, as in the case of noisy environments, where neural timing is disrupted and the neurophysiological representation of speech sounds is distorted (Cunningham, Nicol, Zecker, Bradlow, & Kraus, 2001; Russo, Zecker, Trommer, Chen, & Kraus, 2009; Warrier, Johnson, Hayes, Nicol, & Kraus, 2004). The consequence of unsuccessful auditory object formation is the inability to separate different acoustic signals into appropriate streams. Children with language deficits (Cunningham, et al., 2001), learning difficulties (Warrier, et al., 2004), and those with reading impairment (Anderson, et al., 2010) demonstrated greater delays in temporal resolution than typically developing children with normal hearing in noisy situations but not in quiet (Anderson, et al., 2010). These findings suggest that children with temporal processing difficulties are likely to exhibit an APD in the

form of spatial stream segregation deficits. However, provided appropriate auditory training is in place, improvement in temporal processing as well as phonological representation is possible (Russo, Nicol, Zecker, Hayes, & Kraus, 2005; Warrier, et al., 2004).

Other factors which may impact on the development of the central nervous system (CNS), whether they be maternal (e.g. diabetes, rubella, cytomegalovirus, toxemia); prenatal or perinatal (e.g. hyperbilirubinemia, ototoxicity, low birth weight); or hereditary factors, may also contribute to the development of APD. However, recent evidence suggests there is no correlation between these factors and the development of APD (Dawes, et al., 2008). Although our understanding of the aetiologies of APD remains somewhat premature, some contributing factors have been identified. One clear finding is that APD is often observed in conjunction with other disabilities such as learning and reading disorders, which is reflected in the heterogeneous nature of the disorder.

1.2.3. Characteristics of APD

Children with APD have “difficulties with the perceptual processing of auditory information in the CNS” (Sahli, 2009) despite having normal peripheral hearing (Yalçinkaya & Keith, 2008) and normal intelligence. Auditory processing disorder is characterized by limitations in the recognition, organization, storage, retrieval, separation, discrimination, localization and use of auditory signals. Specifically, these individuals have difficulty with temporal aspects of audition, auditory discrimination, auditory pattern recognition, sound localization and/or lateralization (American Speech-Language-Hearing Association [ASHA], 2005a). Clinically, children with APD may present as having significant difficulties following oral instructions, lateralizing and discriminating incoming sounds, recognizing auditory patterns, discriminating temporal cues (e.g. temporal gap detection), and/or listening when other background noise or competing speech is present. While APD is heterogeneous in nature, the majority of individuals with APD are characterized by the inability to extract degraded acoustic signals (ASHA, 2005b; Chermak, 2002). Thus, for children with APD, one of the most common presenting difficulties is a difficulty understanding speech in the presence of background noise.

Two theoretical models, namely the Buffalo Model (Katz, 1992, 2007) and the Bellis/Ferre Model (Bellis, 2003, 2006), have been developed in an attempt to classify

subgroups of APD based on patterns of assessment results, and associated symptoms or difficulties. These models act primarily as a basis for determining the most appropriate management strategies. “The Buffalo Model” (Katz, 1992, 2007) was developed based on children’s performance on the Staggered Spondaic Word (SSW) test, and on associated learning impairments. The model divides APD into four subtypes: namely the *decoding*, *tolerance-fading memory*, *integration* and *organization* subtypes. Decoding is proposed to be associated with superior temporal lobe dysfunction, in particular the middle to posterior portion. Children with decoding impairments are often slow to respond, have difficulty in accurately processing speech (especially at a phonemic level) and have literacy difficulties (Stecker, 1998). Tolerance-fading memory is proposed to be related to problems in the frontal or anterior portion of the temporal lobe. These children typically have difficulty understanding speech in noisy environments, problems with short term memory and are easily distracted (Katz, 1992, 2007). Integration difficulties are proposed to relate to corpus callosum dysfunction (Katz, 1992), resulting in difficulties in the integration of auditory and visual information, such as spelling and reading (Stecker, 1998). Lastly, organization difficulties, reflected in sequencing problems, are supposed to result from lesions in the frontal lobe, the anterior portion of the temporal lobe, and the postcentral gyrus (Katz, 1992).

In contrast, the “Bellis/Ferre Model” (Bellis, 2003, 2006; Ferre, 2006) places an emphasis on the neuroanatomical and neurophysiological basis of the auditory system and its effect on associated behavioural measures. This model, therefore, takes into consideration a child’s performance on APD assessments, as well as other speech, language and/or academic difficulties he or she may be experiencing. The Bellis/Ferre Model consists of five subtypes of APD, three of which are known as the primary subtypes (*auditory decoding deficit*, *prosodic deficit*, and *integration deficit*), with the other two referred to as secondary subtypes (*associative deficit* and *output organization deficit*). The primary subtypes are presumably caused by inter- and intra-hemispheric dysfunction of the cortex. Children with auditory decoding deficits have difficulty processing speech signals in the presence of background noise, proposed to reflect primary cortex dysfunction (Bellis, 2003, 2006). Children with prosodic deficits exhibit difficulty judging communicative intent and the use of prosody, which is presumed to be caused by right hemispheric dysfunction (Bellis, 2003, 2006). Integration deficit is presumed to be associated with dysfunction of the corpus callosum, resulting in difficulty

with interhemispheric transfer (Bellis, 2003, 2006). The secondary subtypes are supposed to be associated with dysfunction of higher-order functions, such as language and attention (Bellis, 2003, 2006). Children with associative deficits demonstrate auditory-based receptive language impairments, which is associated with problems in the auditory association cortex (Bellis, 2003, 2006); while those with output-organization deficits typically have problems with organizing and following verbal instructions, expressive language disorder and problems with processing speech in noise, and this is presumed to relate to auditory efferent and/or frontal lobe dysfunction (Bellis, 2003, 2006).

While these two models aim to facilitate appropriate management of this inherently heterogeneous disorder, the fact that they are purely theoretical must not be overlooked. There is a paucity of evidence on the relationship between a child's performance on an APD test battery and any associated anatomical lesion or dysfunction. Moreover, the clinical applicability of these two models has been questioned (Jutras et al., 2007). In a retrospective study of 178 cases conducted by Jutras and colleagues (2007), results suggest the Buffalo Model was significantly more applicable than the Bellis/Ferre Model. Specifically, more than 80% of children were classified into one of categories of the Buffalo Model, while less than 10% of the same children fitted within the Bellis/Ferre Model. These findings highlight the heterogeneous nature of APD, and the need for more research to further our understanding of the condition, and enable clinicians to make well informed and evidence-based management decisions.

1.3. Classroom Acoustics

Learning in the typical mainstream academic setting involves auditory-verbal communication. That is, children are expected to learn by listening to and comprehending their teacher's verbally presented instructions (Berg, 1993; Flexer, 1994). In addition, today's educational practices place emphasis on peer teaching and learning, otherwise known as 'incidental teaching' (O. Wilson et al., 2002). Thus, children's ability to hear not only their teacher but their peers in the typical mainstream classroom is particularly important for their academic and social development.

Evidence suggests that young children with normal hearing acuity have more difficulty than normal hearing adults understanding speech in the presence of background noise (Crandell & Smaldino, 2000; Crandell, Smaldino, & Flexer, 1995; Neuman, Wroblewski, Hajicek, & Rubinstein, 2010). Children with normal hearing acuity and auditory processing skills typically require a +10 dB signal-to-noise ratio (SNR) to maximise auditory learning in the classroom setting (Crandell & Smaldino, 2000). It has been proposed that children with APD, as expected, require an even higher SNR of +12 to +20 dB SNR (Crandell, Smaldino, & Flexer, 1995). However, the acoustic conditions in many classrooms is often far poorer than is required for these optimal SNRs.

Furthermore, teachers are adversely affected by poor classroom acoustics as they are often required to raise their voice above the background noise in order to be heard. It is not surprising, therefore, that teachers often suffer from fatigue and voice disorders (Berg, Blair, & Benson, 1996). In a survey by Blake (1994), 90% of the primary school teachers questioned felt that their classrooms were too noisy; 63% felt the noise adversely affected their ability to communicate effectively with their students; and 27% felt that lowering the background noise in the classroom would be beneficial and should be considered. Although Blake (1994) reported that the validity of the questionnaire used in his study was considered low, the results nonetheless demonstrate that teachers are also affected by poor classroom acoustics.

Clearly, optimal classroom acoustics is imperative for learning and for the vocal health of teachers in the academic setting. However, various factors can adversely impact on the audibility, which in turn affects the intelligibility, of the target speech signal. Three particular factors of particular relevance to the everyday educational setting impact on the SNR in a classroom: background noise, distance and reverberation (Beck, Doty Tomasula, & Sexton, 2006). These will be considered in turn.

1.3.1. The Effect of Background Noise

Background noise is defined as any acoustic signals that interfere with the target acoustic signal (Crandell, et al., 1995). Common sources of background noise in the educational setting, as shown in Figure 1, include heating, ventilation and air conditioning (HVAC) systems, computers, printers, other talkers and external noise such as traffic (Classroom Acoustics

Working Group, 2000). The level of background noise in a traditional classroom varies depending on the size and design of the room, the teaching style, the activity of choice and the number of students occupying the room.

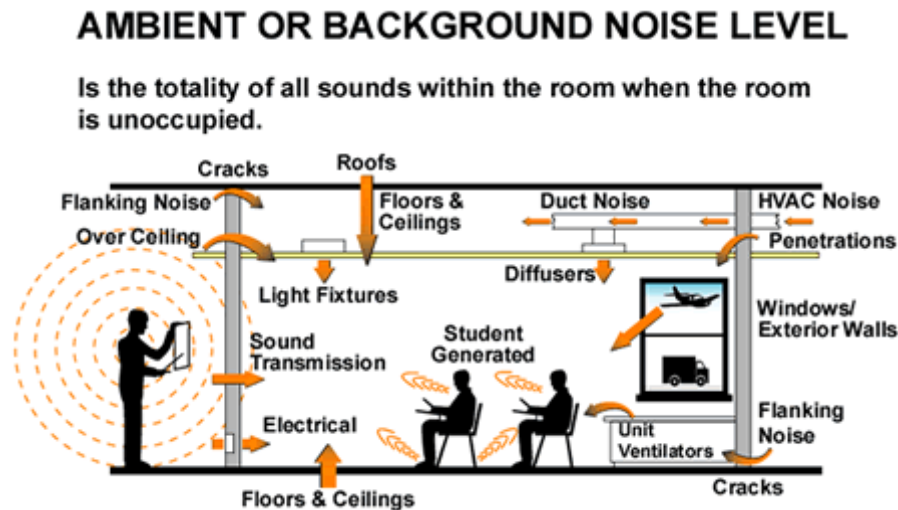


Figure 1. Example of internal and external sources of ambient or background noise in a typical classroom setting (Nixon, n.d.).

Several guidelines regarding classroom designs have been developed recently in Australia, New Zealand and the United States in an attempt to optimize the learning environment by minimizing background noise in classrooms. The American National Standards Institute (ANSI) and the Acoustic Society of America (ASA) standard (ANSI/ASA S12.60-2010) recommend the maximum permissible ambient noise levels in an unoccupied furnished enclosed classroom resulting from exterior- and interior-sources should not exceed an average of 35 and 37 dB(A) per hour respectively (Acoustical Society of America, 2010). Similarly, the Australian/New Zealand Standard (AS/NZ S2107:2000) recommends ambient noise of no higher than 35 dB(A) in an unoccupied classroom (Australian/New Zealand Standard [AS/NZS], 2000). However, many mainstream classrooms continue to have background noise levels that exceed these benchmarks (Choi & McPherson, 2005; Knecht, Nelson, Whitelaw, & Feth, 2002; Nelson & Soli, 2000; Neuman, et al., 2010). Knecht and colleagues (2002) examined a total of 32 unoccupied elementary classroom in eight public schools and found only one of those classrooms met the recommended noise and reverberation criteria set out by the ASA. Interestingly, none of the classrooms with HVAC systems met the acceptable noise level (Knecht, et al., 2002). Although it is less common to find New Zealand classrooms with HVAC

systems installed and more common to find open windows (O. Wilson, et al., 2002), this creates equivalent problems in terms of noise level in the classrooms. In particular, noise generated from lawn mowers, students outside playing sports, as well as noise from other classrooms were perceived by 122 teachers who were surveyed as the most intrusive external noise sources (O. Wilson, et al., 2002).

The most effective masker of a target speech signal is a competing signal of a similar frequency spectrum, namely speech. This has significant implications in the classroom environment, where one of most significant sources of noise is competing speech. This may be more of a problem now, with the introduction of new teaching styles into classrooms, than it has been in the past. In order to create opportunities for children to learn from their peers, many teachers are adopting a more dynamic, interactive teaching style, often involving group work. Since the introduction of this 'incidental teaching' approach, the teaching style in New Zealand has changed dramatically (O. Wilson, et al., 2002), with more emphasis placed on peer teaching and learning. Wilson and colleagues (2002) surveyed 120 New Zealand primary school teachers, who reported that the interactive teaching style, including group and mat work, accounted for an average of 69% of teaching time, while only 12% of teaching time consisted of the conventional lecture-style approach. One major disadvantage of incidental teaching, however, is that student-generated noise is greatly increased. Consequently, the SNR in the classroom is significantly compromised.

Numerous studies have highlighted the detrimental effect of high background noise levels on speech perception in typical classrooms (Nelson, 2003; Nelson & Soli, 2000; Picard & Bradley, 2001; Smaldino & Crandell, 2000; O. Wilson, et al., 2002). Young children were shown to require a much better SNR for speech perception compared to older children. For example, in a word repetition task, Stelmachowicz and colleagues (2000) reported that normal hearing children and normal hearing adults performed similarly in quiet conditions. As audibility decreased to 30%, however, familiar word identification scores in normal hearing five year olds dropped to 30%, while the performance was less significantly affected (85%) in normal hearing adults. Wilson and colleagues (O. Wilson, et al., 2002) reported that high live noise levels was highly correlated with poor speech scores in normal hearing children (mean = 56.8%) and even worse for hearing impaired children (mean = 49.8%). Interestingly, hearing impaired children using personal FM system (attached to hearing aids; mean = 60.2%) out-performed both

normal hearing children and hearing impaired children with hearing aids alone (mean = 25%) in a live speech-in-noise test. The presence of competing sounds, particularly competing speech, thus creates an acoustically challenging environment for children with normal peripheral hearing and auditory processing skills - even more so for those with impaired auditory processing or hearing.

1.3.2. The Effect of Distance

The difference in decibels (dB) between the intensity of a target acoustic signal and the intensity of the background noise is known as the signal-to-noise ratio (SNR). Figure 2 demonstrates the relationship between intensity and speaker/signal source-to-listener distance (SLD). As the SLD increases, the SNR decreases exponentially. This highlights the importance of preferential seating for children with hearing or listening impairments: the closer they sit to the teacher, the better the SNR.

However, preferential seating is not always sufficient to ensure good SNR. Blake (1994) investigated the SNRs in 106 typical New Zealand primary school classrooms occupied by students aged 5 to 7 years by placing a sound level meter at the optimal position for children with impaired hearing (i.e. three meters from the teacher and slightly away from midline). Results revealed poor acoustic conditions in the majority of these classrooms and demonstrated that preferential seating may not be enough to ensure the teacher's speech is heard. In fact, the SNRs obtained from these classrooms varied considerably, ranging from 0 dB to +23 dB. In addition, only 9% of recordings had a SNR of +12 dB or better; and only 4% had a SNR of +15 dB or better.

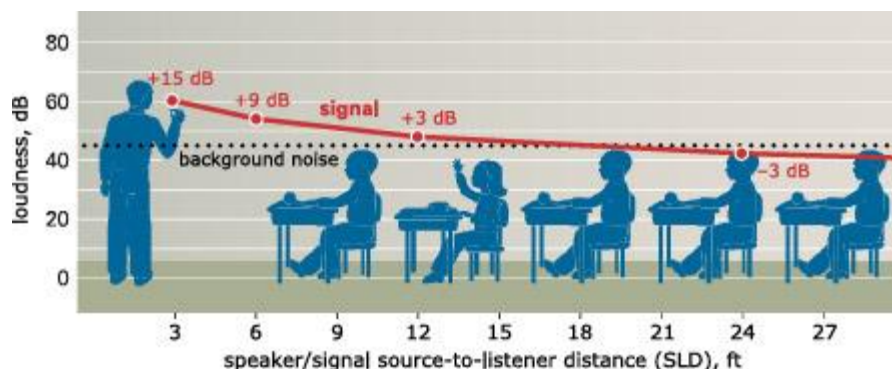


Figure 2. Signal-to-noise ratio (SNR). This figure depicts a traditional lecture-style of teaching in a typical classroom setting wherein the background noise level, represented by the black dotted line, is at a constant level of 45 dB(A) throughout the classroom. At a distance of three feet from the teacher, the intensity level of his voice is approximately 60 dB(A). Based on Newton's Inverse Square Law, the intensity level of the teacher's voice will drop by 6 dB(A) per doubling of the distance, as shown by the solid red line. Therefore, at the distance of 6, 12 and 24 feet the intensity level of the teacher's voice will be 54, 48 and 42 dB(A) respectively. In other words, the SNR becomes less favourable with increasing distance (Guckelberger, 2003). At distances beyond 24 feet, the level of the direct signal is actually below that of the level of the background noise, so for listeners at this distance or beyond, the SNR is actually negative.

1.3.3. Reverberation Time

Reverberation, as shown in Figure 3, refers to the multiple reflections or prolongations of an acoustic signal within an enclosed space with hard surfaces (Kurtovic, 1975). The amount of time (in seconds) it takes for the prolongations to fall by 60 dB is called reverberation time (RT or T_{60}). The duration of RT is affected by the shape, size and sound absorptive quality of the room. Smaller rooms that are well lined with quality sound absorbing materials will have shorter RT and are therefore less reverberant compared to larger rooms with hard surfaces.

The intelligibility of a target speech signal is adversely affected by reverberation, as reflected sounds act to mask the original sound signal by overlapping with it in time (see Figure 3). In other words, the longer the RT, the less intelligible the target speech becomes. For this reason, the Australian and New Zealand standard (AS/NZS 2107:2000) specifies the maximum RT in any classroom is 0.7 seconds at 500 Hz (AS/NZS, 2000). Similarly, the ANSI standard recommends that RTs at 500, 1000 and 2000 Hz for typical classrooms (enclosed volume of

$\leq 283 \text{ m}^3$) and for larger classrooms (enclosed volume of $>283 \text{ m}^3$ and $\leq 566 \text{ m}^3$) should not exceed 0.6 and 0.7 seconds respectively (ASA, 2010).

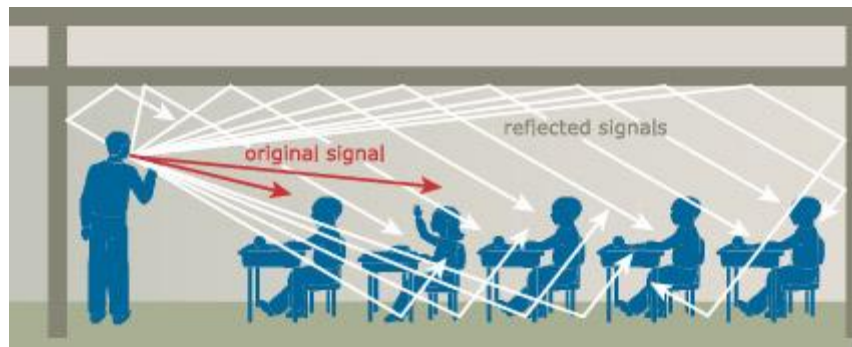


Figure 3. Reverberation. The target speech signal (i.e. the teacher's voice) propagates and reflects off the hard surfaces around the classroom. The reflected signal, or prolongation of the original signal in an enclosed space (i.e. the classroom), is called reverberation. The reflected signals combine and act as a masker of the original signal as the intensity of the reflected signals is often higher than that of the original signal (Guckelberger, 2003).

However, as with the case of background noise, evidence suggests that current classroom acoustic conditions in many schools are yet to meet these recommended benchmarks (e.g. Crandell, et al., 1995; Knecht, et al., 2002; O. Wilson, et al., 2002). For example, 21 out of 32 elementary classrooms from a study by Knecht and colleagues (Knecht, et al., 2002) had reverberation times that were over 0.6 seconds. Classrooms that were rated as being poor listening environments had an average mid-frequency reverberation time of 0.57 seconds on average, whereas an average mid-frequency reverberation time of 0.4 was reported for classrooms that were considered as good listening environments (O. Wilson, et al., 2002). This is not surprising, as evidence shows that the more reverberant a room is, the more difficult it is to understand speech (e.g. Neuman, et al., 2010; O. Wilson, et al., 2002). As described above, children in general require a higher SNR than do adults for speech understanding in noisy environments. For a speech recognition score of 50% in a room with a reverberation time of 0.6 seconds, normal hearing 6 year olds require a SNR of 5.9 dB compared to normal hearing 12 year olds who require a SNR of 2 dB (Neuman, et al., 2010). An even higher SNR is required for better speech understanding.

1.4. *Speech Perception in Noise Tests in APD Assessment*

In order to provide the most appropriate treatment for APD, an accurate assessment is imperative. However, the diagnosis of APD is often difficult and controversial as many other disorders, including autistic spectrum disorder (ASD), attention deficit with or without hyperactivity disorder (ADD/ADHD), learning disorders and/or language disorders (Keith, 2007; Sharma, Purdy, & Kelly, 2009) often coexist with APD. Many currently available tests of speech perception in the presence of noise are limited in their capacity to differentially diagnose APD, as both the testing procedures and the mode of response required from the client is heavily dependent on verbal language (Hall, 2007). Moreover, performance on speech perception in noise tests depends on both cognitive and peripheral processing skills. This makes it difficult to distinguish between APD and other language disorders, a particular problem given the comorbidity of specific language impairment with APD (Sharma, et al., 2009).

Recently, however, the Listening in Spatialized Noise-Sentences (LiSN-S) test (Cameron & Dillon, 2007a, 2007b) has been developed which aims to overcome some of these difficulties. The LiSN-S test is an objective test that assesses a child's ability to utilize binaural cues in speech. Specifically, it examines a child's ability to perceptually discriminate a target acoustic signal from another distracting acoustic signal that is manipulated with respect to the spatial location (0° versus $\pm 90^\circ$ azimuth) and the pitch of the speaker's voice (same as, or different to the target acoustic signal). This ability to differentiate one sound source from another, also known as 'spatial stream segregation', is believed to play an important role in speech perception in noise (Cameron & Dillon, 2008). Listeners with normal auditory processing skills form auditory streams based on the location of the source, the intensity and the spectral or temporal characteristics of the source (Alain, 2007), and are able to attend to the auditory stream of choice (Micheyl et al., 2007). On the other hand, listeners with APD are presumed to have more difficulty forming these appropriate auditory streams, and are therefore less able to take advantage of spatial and pitch cues in the presence of background noise.

The LiSN-S test creates a virtual three-dimensional auditory environment using headphones. The child's speech reception thresholds (SRTs; the ability to correctly repeat target sentences during simultaneous presentation of distracting speech) obtained from the four different test conditions (as shown in Figure 4) are compared, and a score of two standard deviations or below is considered outside the normal range for that child's age. The test uses

within-subject comparisons across the four different test configurations to determine the impact of spatial and speaker differences on a child's speech reception abilities. By measuring performance as a difference between scores in varying conditions, the influence of differing linguistic and cognitive skills across subjects is minimized. This makes the test a useful clinical tool which facilitates the differential diagnosis of APD, and importantly, the recommendation and implementation of appropriate management strategies.

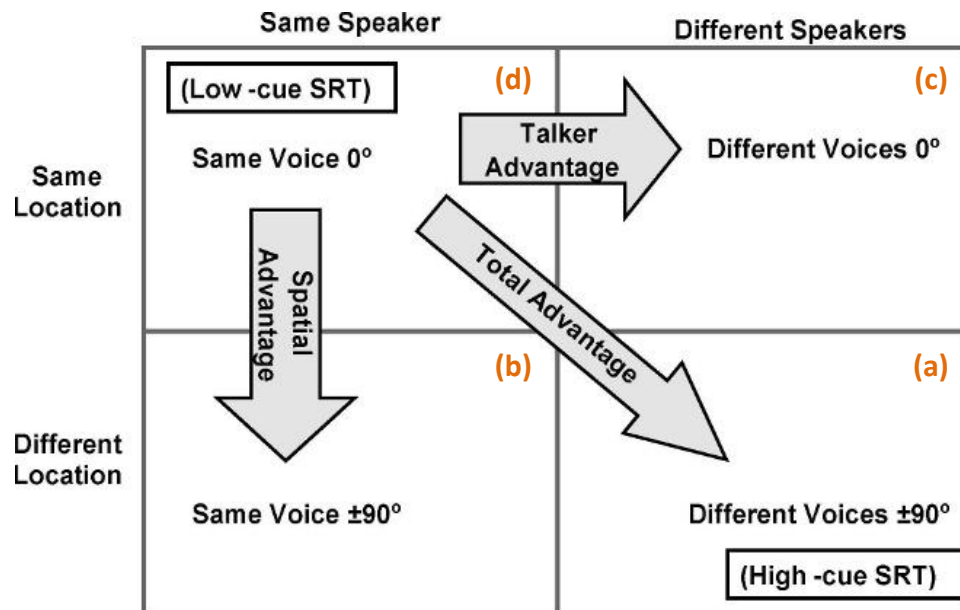


Figure 4. The four different conditions in the LiSN-S test, where the competing sentences are presented at (a) $\pm 90^\circ$ azimuth with a different voice to the target speaker (i.e. high-cue SRT); (b) $\pm 90^\circ$ azimuth with the same voice as the target speaker; (c) 0° azimuth with a different voice as the target speaker; and (d) 0° azimuth with the same voice as the target speaker (i.e. low-cue SRT).

1.5. Management of APD

As the nature and the impact of APD differs from one individual to another, intervention for APD should be based on the individual's assessment profile (ASHA, 2005c; Rosenberg, 2002). Early implementation of intervention is crucial in this population in order to maximise outcomes by capitalising on the plasticity of the young CNS. Management of APD in children typically involves a combination of direct remediation of APD (i.e. formal and informal auditory training), provision of various compensatory strategies (i.e. listener- and speaker-based adaptation), and enhancement of the signal and/or the acoustics via the implementation of

sound field system (Bellis, 2002); personal frequency-modulated (FM) devices (Updike, 2005); and/or hearing aids (HAs; Kuk, Jackson, Keenan, & Lau, 2008) in the learning or communication environment.

Normally hearing children require a 10 dB better SNR than adults to perform at the same level on a speech perception task (Smaldino & Crandell, 2000). However, as discussed above, such good SNRs are rarely found in the mainstream classroom setting. Additionally, exceptional difficulty hearing in background noise is reportedly the most common complaint in children with APD (Chermak, Somers, & Seikel, 1998). Therefore, the use of technology to enhance the SNR in the classroom is deemed appropriate to alleviate speech perception difficulties in background noise and benefit all children in the classroom, but particularly those children with APD. Due to the heterogeneous nature of APD, it is reasonable to assume that the use of amplification to enhance SNR may be more beneficial to certain subgroups of this population and not others.

1.5.1. Hearing aids and APD

Hearing aids have been suggested as an option for children with APD to help improve speech perception in background noise. It has been proposed that the use of hearing aids may be a more appropriate choice than an FM system as they are more portable and do not require the speaker to use a microphone (Kuk, et al., 2008). However, the benefits of hearing aids on speech perception in noise for individuals with APD depend on the specific hearing aid.

Kuk and colleagues (2008) examined the use of bilateral behind-the-ear (BTE) digital hearing aids on 14 normal hearing 7 to 11 year old children who were diagnosed with APD and /or ADHD. All children were required to wear bilateral, minimal gain, open fitting hearing aids coupled with slim tubes for a period of six months. All hearing aids had three channels with both slow-acting wide dynamic compression (WDRC) and noise reduction. The hearing aids included a “quiet” (i.e. the use of an omnidirectional microphone with the noise reduction feature deactivated) and a “noise” (i.e. the use of a directional microphone with the noise reduction feature activated) programme. The children were blinded to the nature of the programmes but were encouraged to wear their hearing aids with their preferred programme by experimenting with the two programmes at school and at home. Speech recognition in quiet

and in noise were evaluated at 2 weeks, 3 and 6 months following initial fitting using the NU-6 word lists presented via sound field speakers with the hearing aids set in (a) omnidirectional microphone only; (b) omnidirectional microphone with noise reduction activated; and (c) directional microphone with noise reduction activated. Amplified speech alone was found to have no effect on the children's speech recognition in noise, while the use of omnidirectional microphone with the noise reduction feature activated reportedly improved the children's performance in noise. All children demonstrated significant improvement in their speech understanding in noise when a directional microphone was used in conjunction with noise reduction. Anecdotally, a majority of the children reported that they could hear the teacher and their parents "a lot better", and both teachers and parents reported positively regarding the hearing aid trial.

While the results from this study suggest that a digital hearing aid with a directional microphone and a noise reduction feature may assist children with APD in understanding speech in noise, several limitations were noted. Firstly, the small sample size and the lack of a control group make generalisations regarding the use of hearing aids in children with APD difficult. A more pragmatic concern regards the cost of a hearing aid, as compared to other management strategies such as auditory training programmes or other technologies (e.g. FM systems). Indeed, only three of the 14 participants in the Kuk study purchased the hearing aids at the completion of the study, despite the reported overall positive response to the trial. Finally, and most importantly, hearing aids, even those with directional microphones and noise reduction features, are not able to overcome the impact of background noise, distance and reverberation time as effectively as a personal FM system – which is why most hearing-impaired children pair their aids with an FM system while in the classroom.

1.5.2. Sound field Systems and APD

An FM system consists of a microphone transmitter and a receiver which picks up the signal from the microphone transmitter via a specified FM channel. The receiver may be connected to sound field speakers or worn as an individual ear-level device. Previous studies have compared the speech perception benefits of FM sound field systems and personal, ear-level FM systems under various acoustics conditions.

Sound field FM systems have been demonstrated to provide benefits as measured by both academic performance (Ray, Sarff, & Glassford, 1884; Sarff, Ray, & Bagwell, 1981) and speech perception (Mendel, Roberts, & Walton, 2003) in normal hearing children. For example, in a two year longitudinal study, normal hearing children ($n = 64$) who received sound field amplification were found to develop speech perception skills significantly earlier than their control peers ($n=64$) (Mendel, et al., 2003). However, little is known about the effectiveness of sound field FM systems in children with APD.

1.5.3. Personal Frequency-Modulated System and APD

The benefits of personal FM systems have been widely demonstrated in hearing impaired children but there are fewer studies of the effectiveness of personal FMs in children with APD (e.g. Friederichs & Friederichs, 2005; Johnston, et al., 2009). Firstly, FM systems reduce the adverse effects of distance, reverberation, and noise, which results in a cleaner auditory signal with a 20 to 30 dB improvement in signal-to-noise ratio (SNR) that is presented to the listener (Crandell & Smaldino, 2002; Crandell & Smaldino, 2000). By placing a microphone near to the speaker's mouth, personal FM devices reduce the sound pressure level of reflected sounds relative to that of the source, thus, making the listening task easier, less stressful, and more enjoyable for the listener (Beck, et al., 2006). Findings from studies of children with hearing loss also suggest those who scored a minimum of 40 to 60% in speech discrimination in quiet (Boothroyd & Iglehart, 1998) can improve their performance by up to 25% in a classroom with an ambient noise level of less than 35 dB (A) and a RT of less than 0.6 seconds if using an ear-level FM system. Weihing (2005) reported that, regardless of age, the use of an FM system alone can provide considerable improvements in auditory performance for the majority of hearing impaired people, even those with extremely poor unaided auditory performance. While this study focused on individuals with hearing loss rather than with APD, the report highlighted the importance of SNR as a major factor in listening success.

Secondly, and perhaps more importantly, FM systems provide consistent auditory stimulation that is crucial in promoting the maturation or development of the auditory pathways (Johnston, et al., 2009). In one study, the improvement in speech perception in normal hearing children who were exposed to prolonged stimulation via FM systems happened much earlier than in those who did not receive stimulation (Mendel, et al., 2003). Similar

improvements in speech perception in both quiet and in noise following a period of prolonged stimulation via personal FM systems in a group of APD children were maintained even after the FM systems were removed (Johnston, et al., 2009). The provision of consistent stimulation, therefore, seems to be associated with permanent improvements in auditory perception abilities.

There is abundant evidence from pre-attentive far-field cortical evoked potential studies demonstrating neuroplasticity of the human central auditory system following sensory stimulation (e.g. Kraus et al., 1995; Neuman, 2005; Song, Skoe, Wong, & Kraus, 2008; Tremblay & Kraus, 2002; Ylinen et al., 2009). For example, Kraus and colleagues (1995) demonstrated a significant improvement in the mismatch negativity (MMN) evoked potential, a pre-attentive event related cortical potential, in 13 normal hearing adults following six hours of behavioural training on speech discrimination. Russo and colleagues (2005) reported more precise stimulus encoding in nine children with learning disorders who received eight weeks of Earobics training when compared to their control pairs who demonstrated no changes. Warrier and colleagues (2004) also reported similar findings in a group of children with learning disorders following an eight-week auditory training programme. Clearly, neurological changes in the central auditory pathways can occur following both short-term and long-term auditory training. However, while it is important to know that the central auditory system is amenable to modification via sensory stimulation, these neurological changes can often precede behavioural changes. Thus, it may be more clinically appropriate to use behavioural testing to track changes following a particular treatment or intervention.

Although many advantages are associated with FM, there is paucity of empirical data on the use of FM devices in normal hearing children with APD, particularly those with specific spatial processing deficits. Evidence suggests that FM systems are effective in individuals who demonstrate difficulties in monaural low redundancy (MLR) speech tests and/or dichotic listening tests (Bellis, 2003; Johnston, et al., 2009; Rosenberg, 2002). Johnston and colleagues (2009) fitted the Phonak EduLink FM system to ten children between the ages of eight and 15 who were diagnosed with APD and reported significant improvements in speech understanding in both quiet and noise following 5 months of FM use. More importantly, the children's speech perception in quiet improved regardless of whether they were wearing the FM devices or not, following the 5 month stimulation period. This suggests that prolonged usage of personal FM

devices may improve the children's auditory processing abilities. Anecdotally, parents and teachers also report benefits of personal FM devices. For example, parents and teachers of children with APD from Friederichs and Friederichs's (2005) study reported significant improvement in the children's speech understanding, overall academic performance and behaviour following the use of personal FM devices for a year.

As the LiSN-S test involves both a low redundancy speech signal and dichotic listening skills, the use of a personal FM system would seem a most appropriate management strategy for children who perform poorly on this test compared to their peers, and are identified with a spatial stream segregation disorder.

1.6. Statement of the Problem

Auditory processing disorder is a heterogeneous condition in which the individual's ability to process incoming auditory stimuli is impaired, despite normal hearing sensitivity. This study focuses on a particular type of auditory processing deficit - spatial stream segregation deficit - as determined by the LiSN-S test.

Although FM devices have been shown to be an effective strategy in enhancing the SNR and improving speech understanding of individuals with elevated hearing sensitivity (Crandell, et al., 1995), there is a paucity of empirical data on the use of personal FM devices in children with APD (Beck, et al., 2006; Bellis, 2002; Rosenberg, 2002). The purpose of this study is to identify children with spatial stream segregation difficulties by administering the LiSN-S test and to investigate the effectiveness of an ear-level personal FM device on improving the ability of these children to listen in background noise. It is important to note that the children in this study, both the control group and FM group, all had severe specific learning disabilities (SLD) and attend a small private school specifically for children with severe dyslexia, dyspraxia or other SLDs. All children experienced significant difficulties emotionally and/or academically in the mainstream school system before attending their current school, where they receive speech and language therapy, occupational therapy and social skills training as part of their programme. Thus, this school environment offers a unique opportunity to control for many factors that may otherwise have varied widely across participants had they all attended different schools: the classroom acoustics, the teachers/teacher aides involved in the study, the

educational and extra-curricular experiences of the children, and the type and quantity of therapies and interventions other than FM systems being administered.

It is hypothesized that the use of a personal ear level FM system will improve the spatial stream segregation abilities of children with APD. Specifically, the following research questions and hypotheses are proposed:

1. Do children with APD show improved spatial stream segregation ability as measured by the LiSN-S test following eight weeks of use of a personal ear-level FM system?

It is hypothesized that children with APD will improve in their ability to segregate spatial streams as measured by the LiSN-S test, following eight weeks of acoustic stimulation via a personal, ear-level FM system.

2. Do children with a spatial stream segregation deficit show decreased spatial stream segregation ability as measured by the LiSN-S at eight weeks following the discontinuation of FM use, or will any gains made during the stimulation period be maintained?

It is hypothesized that at eight weeks following the discontinuation of use of a personal FM system, children with a spatial stream segregation deficit will maintain their improved ability to segregate spatial streams as measured by the LiSN-S test.

3. Do children with a spatial stream segregation deficit show improved reading accuracy, comprehension of connected text and rate of reading following eight weeks of FM use?

It is hypothesized that, following eight weeks of acoustic stimulation via a personal FM system, children with a spatial stream segregation deficit will improve in their reading accuracy, comprehension of connected text and rate of reading.

4. Do children with a spatial stream segregation deficit show improved phonological processing/awareness skills following eight weeks of FM use?

It is hypothesized that, following eight weeks of acoustic stimulation via a personal FM system, children with a spatial stream segregation deficit will improve in their phonological processing/awareness skills.

5. Do classroom teachers see an improvement in auditory performance and auditory behaviours of children with a spatial stream segregation deficit in the classroom following eight weeks of FM use?

It is hypothesized that classroom teachers will report an improvement in auditory performance and auditory behaviours of children with a spatial stream segregation deficit in the classroom following eight weeks of FM use.

6. Do teachers see a change in auditory performance and auditory behaviours of the children with a spatial stream segregation deficit in the classroom at eight weeks following the discontinuation of FM use?

It is hypothesized that classroom teachers will report no change in auditory performance and auditory behaviours of children with a spatial stream segregation deficit at eight weeks following discontinuation of use of a personal FM system.

7. Do children with a spatial stream segregation deficit see an improvement in their auditory performance following eight weeks of FM use at school?

It is hypothesized that children with a spatial stream segregation deficit will report an improvement in their own auditory performance following eight weeks of FM use at school. Specifically, it is hypothesized that the children with a spatial stream segregation deficit will report that the FM system is most beneficial when listening in the presence of speech and/or background noise.

CHAPTER 2. METHODOLOGY

2.1. *Participants*

A total of 24 children and four teachers from a private primary school participated in this study. Two children were later excluded from the study: one child was difficult to test due to hypersensitivity to auditory stimuli; the other fell outside the target age range (i.e. 7;0 to 11;11 years). The remaining children, 19 boys and 3 girls, were between the age of 7;3 and 11;6 years. All children from the school have specific learning disabilities (SLD) and had experienced difficulties emotionally and/or academically within the mainstream school system. Thus, all children receive speech and language therapy, occupational therapy and social skills training as part of their school programme. The school consists of two classes, namely room 1 with a mean age of 8 years 10 months ($SD = 0.83$ years) and room 2 with a mean age of 10 years 4 months ($SD = 0.75$ years). Each class has two teachers in the mornings, while a teacher and a teacher-aide are responsible in the afternoons. Classroom activities are predominantly carried out with the children in pairs or in small groups of six and with both staff teaching simultaneously in each individual classroom. All parents and teachers were provided with information regarding the study prior to the beginning of the study as shown in Appendices 2 to 5. Informed consent was obtained from the teachers, parents/caregivers and children (see Appendices 6 to 8). The parents/caregivers also completed a questionnaire with reference to their child's birth, medical, speech and language and audiological history, and their concerns regarding their child's listening behaviours as shown in Appendix 9.

2.2. *Materials*

2.2.1. *FM Devices*

All FM participants were fitted with Phonak iSense Micro wireless receivers bilaterally. The iSense Micro receiver was chosen due to its lightweight body, which allowed for more comfortable wear; and because of its open fit design which allowed the aided participants to listen to the unamplified voices of other children and teachers, as well as their own voices. The technical data of the receivers are listed in Table 1. Each teacher was provided with a Phonak

Inspiro transmitter coupled with a lapel microphone. All FM devices used in this study, including batteries, were provided by Phonak Communications.

Table 1. Technical data for iSense Micro Receivers (Phonak AG, 2008).

Specifications	
<i>Frequency bandwidth</i>	100 to 5800 Hz
<i>Maximum output limiting</i>	112 dB SPL (Ear simulator); 102 dB SPL (2cm ³)
<i>SNR</i>	Variable (up to 27dB) as it is a dynamic system
<i>Power Management</i>	312 battery; 40 to 50 hours

2.2.2. Audiometric Equipment

Pure tone audiometric screening was performed using an Interacoustics AS608 portable screening audiometer with circumaural Sennheiser HDA 200 audiometric headphones. Tympanometry was performed using the Interacoustics MA4 portable middle ear analyzer or the GN Otometrics Madsen OTOflex 100 diagnostic immittance device.

2.2.3. Quantitative Assessments

The effect of the use of an FM system on the participants' spatial stream segregation skill was measured using the LiSN-S test. Reading, literacy and phonological awareness skills were also assessed. All assessments were administered in a quiet assessment room at the school by either the author or her primary supervisor (LiSN-S test only). Participants did not wear their FM devices at the time of testing.

2.2.3.1. Listening in Spatialized Noise-Sentence Test (LiSN-S Test)

The LiSN-S test (Cameron and Dillon, 2007a) was presented via the Sennheiser HD215 circumaural headphones connected to the headphone socket of a Sony VAIO VGN-FW53GF laptop computer via a Phonak Sound Card. The LiSN-S test was administered to the participants in both the control group and the FM group before, immediately after and eight weeks after the FM trial period in a quiet room at the school. All four subtests of the LiSN-S test were administered to assess the children's ability to understand speech in the presence of competing speech and to measure the effect of the use of the FM system on the FM participants' ability to segregate spatial streams. Relative to the child, the competing speech was presented at

(1) $\pm 90^\circ$ with a different voice; (2) $\pm 90^\circ$ with the same voice; (3) 0° with a different voice; and (4) 0° with the same voice as the target speech. A speech reception threshold (SRT) was obtained under each of the four conditions. The “spatial advantage” score reflected the child’s ability to make use of spatial cues in speech understanding and was calculated as the difference between his/her SRTs in conditions (2) and (4). The “talker advantage” score was calculated as the difference between the SRTs in conditions (3) and (4), and reflected the child’s ability to use voice cues in speech perception. Lastly, the “total advantage” measured the child’s ability to use both spatial and voice cues in speech understanding by calculating the difference between the SRTs in conditions (1) (i.e. high cue SRT) and (4) (i.e. low cue SRT).

2.2.3.2. *Neale Analysis of Reading Ability 3rd edition (NEALE-3)*

The effect of FM use on the children’s reading accuracy and comprehension of connected text were assessed before and immediately after the eight-week FM trial using the NEALE-3. It was individually administered in the quiet assessment room by a qualified speech and language therapist (the author) on either the same day or within one week of LiSN-S test administration. The children were required to read aloud short stories of increasing difficulty until 12 or more errors were made on a passage. The word was given to the participant if he/she did not respond within four seconds. The child’s comprehension was evaluated via a series of questions regarding the content of the story. A reading age as well as percentile rank was then calculated for reading accuracy and comprehension.

2.2.3.3. *Queensland University Inventory of Literacy (QUIL)*

Four subtests from the QUIL (Dodd, Holm, Oerlemans, & McCormick, 1996) were administered to all children before and immediately after the eight-week FM trial to assess their phonological awareness. Specifically, the following four subtests were administered: (1) Non-word spelling; (2) Syllable Segmentation; (3) Syllable Identification; and (4) Phoneme Segmentation. The procedure and scoring for each subtest are detailed in Table 2. The raw score obtained from each subtest was converted to standard score for comparison to the norms.

Table 2. Detailed information regarding the administrative procedure and scoring method of the Non-word Spelling, Syllable Segmentation, Syllable Identification and Phoneme Segmentation subtests from the Queensland University Inventory of Literacy (QUIL; Dodd, et al., 1996) subtests.

Subtest	Procedure and Scoring
1. Non-word Spelling	In this subtest, children were asked to spell between 12 and 24 made up words depending on their year level/grade. Each word was repeated once and the child was given as much time as he/she required. Each correct word was worth one point and no points were given for any implausible spelling.
2. Syllable Segmentation	In this subtest, children were asked to count the number of syllables in 12 real words. For those who were not able to count, verbal separation of syllables was accepted. No repetitions were allowed. Each correct response was given one point and no points were given for any incorrect responses.
3. Syllable Identification	In this subtest, children were asked to listen to pairs of bi-syllabic words and decide whether the beginning, the end or neither of the parts sounded the same.
4. Phoneme Segmentation	In this subtest, children were asked to listen to a mixture of real and made-up words and were required to count the number of phonemes in the word. As with the Syllable Segmentation subtest, verbal separation of phonemes was accepted for those who were not able to count.

2.2.3.4. Comprehensive Test of Phonological Processing (CTOPP)

Four subtests from the CTOPP (Wagner, Torgesen, & Rashotte, 1999) were administered to the children from the FM group before, immediately after, and eight weeks following the 8-week FM trial to assess their phonological memory and rapid naming skills. Phonological memory requires temporary storage of phonologically coded information in the short-term or working memory, while rapid naming requires the completion of a series of repetitive tasks in a rapid manner by retrieving phonological information from permanent or long-term memory. Details of the procedures are described in Table 3. The raw scores obtained from each subtest

were converted to standard scores, and the sums of the standard scores of each of the two subtests from the two categories (i.e. phonological memory and rapid naming) were converted into composite scores for comparisons to the norms.

Table 3. Detailed information regarding the administrative procedure and scoring methods for the phonological memory subtests (i.e. Memory for Digits and Non-word Repetition) and rapid naming subtests (i.e. Rapid Digit Naming and Rapid Letter Naming) from the CTOPP (Wagner, et al., 1999).

Subtest	Procedure and Scoring
1. Memory for Digits	The children were asked to listen and repeat a list of increasingly long series of numbers in the exact order as read aloud by the author. Three practice items, with feedback where appropriate, were given to the children prior to the administration of the test items. One point was given for an accurate response and no points were given for inaccurate responses. No further items were administered when the child had made 3 consecutive errors.
2. Non-word Repetition	The children were asked to listen to and repeat a list of non-words of increasing length and complexity as read aloud by the author. Three practice items, with feedback where appropriate, were given to the children prior to the administration of the test items. One point was given for an accurate response and no points were given for inaccurate responses. No further items were administered once the child had made 3 consecutive errors.
3. Rapid Digit Naming	The children were asked to read aloud a page filled with numbers (as presented in the assessment booklet) as quickly and as accurately as they could. A practice page with a list of five numbers was given to the children prior to the administration of the test items. The time it took the child to read all the numbers was recorded and up to four errors were accepted. A total of two pages of numbers (i.e. list A and list B) were read by each child.
4. Rapid Letter Naming	The children were asked to read aloud a page filled with letters (presented in the assessment booklet) as quickly and as accurately as they could. A practice page with a list of five letters was given to the children prior to the administration of the test items. The time it took the child to read all the letters was recorded and up to four errors were accepted. A total of two pages of letters (i.e. list A and list B) were read by each child.

2.2.4. *Qualitative Assessments*

A total of two questionnaires and four rating scales were completed by the classroom teachers. In addition, a questionnaire developed by the author was also completed by the children from the FM group. These are described individually in detail in the following sections.

2.2.4.1. *Children's Auditory Performance Scale (C.H.A.P.S.)*

The C.H.A.P.S. (Smoski, Brunt, & Tannahill, 1998) is a questionnaire designed to assess the observed auditory behaviours of children aged 7 years or older. It consists of 36 questions, which examine the child's auditory memory and auditory attention span, as well as their ability to listen in an environment that is noisy, quiet, ideal or in the presence of multiple inputs (e.g. auditory and visual or tactile etc.). Each question consists of a rating scale from +1 (i.e. less difficulty compared to other children of similar age and background) to -5 (i.e. cannot function at all). A raw score for each condition is obtained and averaged, where scores below -1 are considered to be below the normal range and are indicative of a possible auditory processing disorder.

2.2.4.2. *Fisher's Auditory Problems Checklist*

The Fisher's Auditory Problems Checklist (Fisher, 1980) is a screening tool designed to identify children at risk of having auditory processing difficulties. It consists of a total of 25 statements describing various observable behaviours or difficulties and the examiner is required to check all statements that apply to the child of interest. A grade score is obtained by converting the sum of all unchecked items into a percentage. Further testing is recommended for children who obtain scores of 72.5% or below. The teachers in this study completed a Fisher's Auditory Problems Checklist for each child in the FM group before, immediately after and eight weeks following the FM trial.

2.2.4.3. *Goal Attainment Scaling (GAS)*

The GAS, first developed by Kirusek and Sherman (1968), is a symmetrical five-point scale developed to assess achievement over an extended period using individually set goals. While it was originally developed to be used within the health contexts to evaluate treatment outcomes (e.g. McLaren & Rodger, 2003; Turner-Stokes & Williams, 2010), GAS has also been

used for evaluating academic achievements in educational contexts (e.g. Carr, 1979; Parilis, 1995; Roach & Elliott, 2005).

Each scale is individualised for each student, where the expected/realistic level of achievement following a specific treatment is given the score of '0'. Achievement level 'slightly' and 'much' better than expected are represented by the score of '+1' and '+2' respectively, whereas scores of '-1' corresponds to achievement level 'slightly' lower than expected and '-2' corresponds to current ability or achievement level 'much' lower than expected (Bovend'Eerd, Botell, & Wade, 2009). Well defined objectives for each of the five levels are crucial in GAS (see Appendix 10 for an example). Each level must be written in a specific, measurable, achievable, realistic/relevant and timed (i.e. SMART) manner (Schut & Stam, 1994) and they must also be symmetrical in order for the scale to be valid.

2.3. *Study Design*

An A-B-A comparative group design (control group vs. FM group) was employed to determine the effectiveness of the use of personal FM systems as an intervention and its effects on spatial stream segregation, literacy and PA. This study was approved by the University of Canterbury Human Ethics Committee (see Appendix 1).

2.4. *Procedure*

The timeline of this study is shown in Figure 5. All participants' hearing was assessed prior to the fitting of the FM systems using a standard audiological screening assessment battery in a quiet room at the school. This included otoscopy, screening pure tone audiometry at octave frequencies from 250 to 8000 Hz and screening tympanometry. All except one children demonstrated normal middle ear compliance and pressure. One child demonstrated significant reduced middle ear compliance with low volume type B tympanograms and was promptly referred to an otolaryngologist. The child was treated with ventilation tubes and was therefore included in the study with high volume type B tympanograms.

In addition, baseline measures of the child's spatial stream segregation, literacy, comprehension and phonological awareness skills were obtained within two weeks of the initial audiological assessment. Based on their performance on the LiSN-S test, the children were

assigned to either the control group (n=12) or “FM” group (n=10; n=5 in room 1 and n=5 in room 2). Specifically, the FM group consisted of participants who demonstrated (a) a significant deficit in spatial stream segregation (i.e. two standard deviations or below their aged norms in the ‘spatial advantage’ score) or (b) significant deficit (i.e. two standard deviations or below their aged norms) in the ‘High Cue’ AND ‘Low Cue’ conditions. All other participants with normal spatial stream segregation abilities were assigned to the control group.

Prior to the FM trial, a single set of GAS goals were developed in consultation with the author under the guidance of Dr. Fiona Graham (an experienced GAS user and Occupational Therapist from the University of Otago) for each participant in the FM group (see Appendix 10 for an example). At this point, the teachers also individually completed the C.H.A.P.S. and the Fisher’s Auditory Problems Checklist for each participant in the FM group under the guidance of the author.

Each participant in the FM group was provided and fitted with Phonak iSense Micro wireless FM receivers bilaterally and was instructed to wear the devices continually during class time for eight consecutive weeks. Due to the availability of FM systems at the time of the commencement of the study, three out of ten participants were initially fitted with the Phonak iSense Classic FM hardwired receivers, which were then replaced with the Phonak iSense Micro receivers in the second week of the trial (see Figure 5). The classroom teachers were instructed to wear the Phonak Inspiro FM transmitters coupled with lapel microphones. They were also provided with instructions on the operation of the FM system before the FM trial commenced. Due to the structure of the classroom activities (see Section 2.1), each transmitter was set with a different channel and was tested to ensure there was no interference between the transmitters. The “multitalker network” feature on the Phonak Inspiro transmitter was deemed inappropriate due to the structure of the classroom activities and was consequently not used throughout the FM trial.

Upon the completion of the eight-week trial with the FM devices on, all participants were reassessed on their spatial stream segregation abilities, their phonological awareness, and their literacy and comprehension skills. At this point, all FM participants completed a questionnaire regarding their experience with the FM systems, as shown in Appendix 11. The teachers also individually evaluated the individual performance of each child from the FM

group using the C.H.A.P.S. and Fisher's Auditory Problems Checklist; while the GAS was rated by the two teachers either collaboratively or individually from each classroom. Finally, at eight weeks post-FM trial, the teachers again assessed each child from the FM group individually using the C.H.A.P.S. and Fisher's Auditory Problems Checklist; and follow-up assessment of all children's spatial stream segregation skills using the LiSN-S test was completed.

2.5. *Statistical Analysis*

The data were evaluated as a function of individual performance, as well as group performance. Objective data were submitted to a series of two-way repeated measures analyses of variance (RM ANOVAs) to examine differences in group performance (two levels: FM and control) for each test across the three sampling points (three levels: pre-trial, post-trial and follow-up). Scores obtained from the Fisher's Auditory Problems Checklist and the C.H.A.P.S. from Room 1 and 2 were submitted separately to both a series of two-way RM ANOVAs to examine inter-rater differences (two levels: Teacher A/B and Teacher C/D for Room 1 and 2 respectively) across the three sampling points; and to a one way RM ANOVA to examine the FM participants performance as a group across the three sampling points. Descriptive statistics were used to evaluate each participant's performance across the three sampling periods and to evaluate the information obtained from the GAS. All statistical analyses were performed using SigmaStat 3.5 (Systat Software, Inc., USA), with the significance level set at $p < 0.05$. All significant effects were followed up by post-hoc pairwise comparison procedures and plotted graphically using Microsoft® Office Excel® 2007 (Microsoft®).

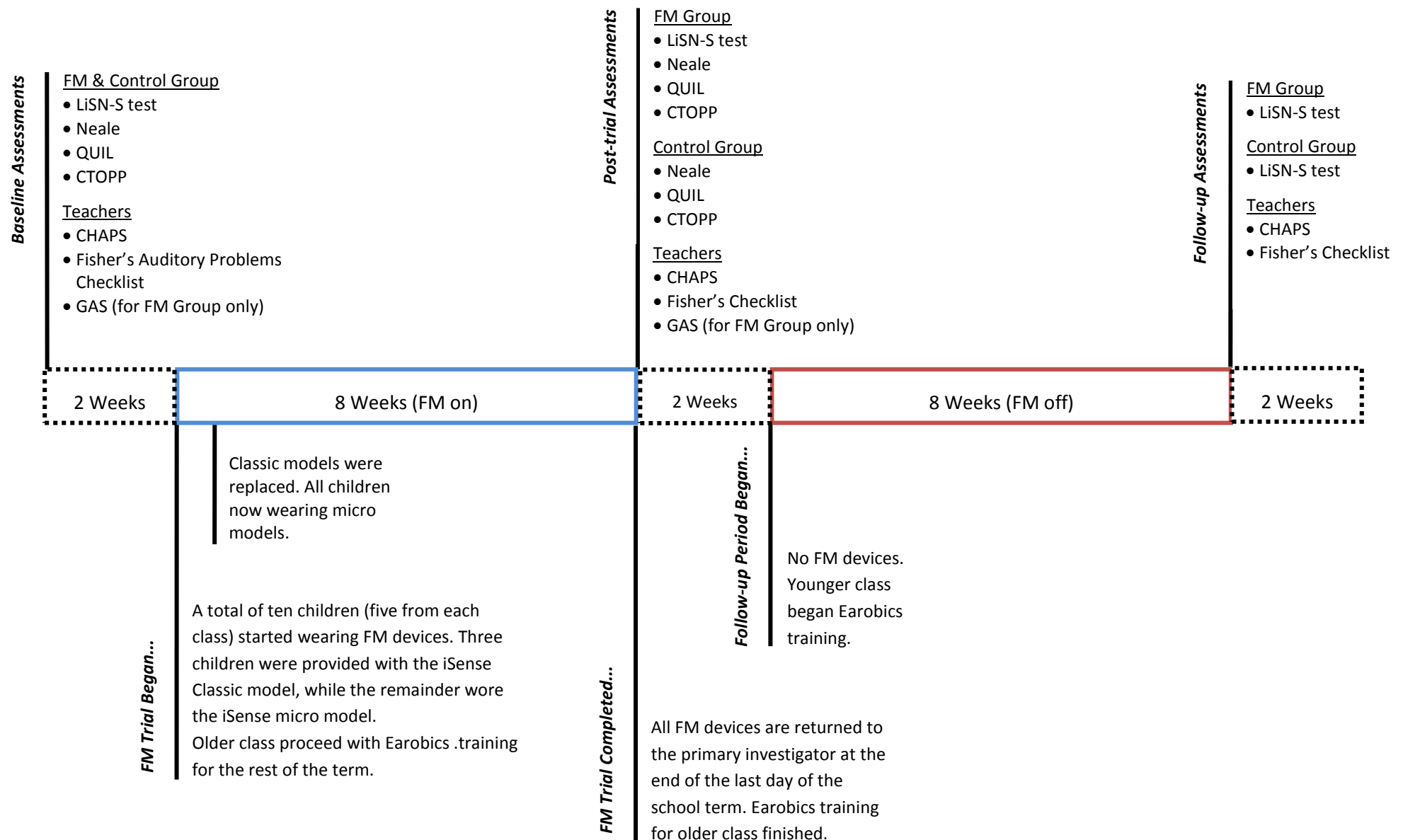


Figure 5. Timeline depicting the individual sampling points and the assessment battery over a 6-month period.

CHAPTER 3. RESULTS

3.1. Overview

The statistical results from a series of one-way repeated measures analysis of variance (RM ANOVAs) and two-way RM ANOVAs performed on group data of the objective and subjective data gathered across the three sampling points are presented in the following sections.

3.2. Findings for Objective Assessments

As briefly discussed in Section 2.5, the statistical analyses for objective assessments consisted of two independent variables, namely “group” (2 levels: control x FM) and “sampling point” (3 levels: pre-trial x post-trial x follow-up). “Group” effect refers to between-group differences; and “sampling point” effect refers to changes in relation to the FM trial period. The effect of the interaction between these two factors is referred to as the “group-by-sampling point” effect.

3.2.1. Effects of FM Use on LiSN-S Test Performance

The control and FM participants’ individual spatial advantage scores from the LiSN-S test obtained at the three sampling points are shown in Table 4 on the following page. In general, the use of personal FM devices was associated with an improvement on the spatial advantage scores, as shown in the performance of the FM participants. Five out of eight children from the FM group (Participants 3, 15, 17, 22 and 24) showed an improved spatial advantage score immediately following the 8-week FM trial (see Table 4). Their scores shifted from being outside normal limits to being within normal limits following the trial. This improvement was maintained at 8-weeks following the withdrawal of the FM systems. Similarly, the two children who were included in the study on the basis of their low and high cue SRT scores showed improved scores for both low and high cue SRT immediately following the 8-week FM trial, with their scores shifting from being outside normal limits to being within normal limits following the trial, and these scores were maintained at the follow-up time point. Three children from the FM group (Participants 5, 12 and 14) remained 2 SD outside normal limits at both the post-trial and follow-up time points. It was also noted that the spatial advantage score for two

children from the control group had worsened throughout the study, with one falling outside normal limits at the post-trial time point and the other at both the post-trial and follow-up time points.

Table 4. Control and FM participants' individual spatial advantage scores (shown in SD) from the LiSN-S test across the three sampling points. Scores of two SD and below are considered outside normal limits and are shown in red; scores within normal limits are shown in green. Participants 2 and 9 from the FM group demonstrated spatial advantage scores within normal limits; however, both their low cue and high cue SRTs were outside normal limits at their pre-trial assessments. Their performances on these two conditions over the three sampling points are shown at the bottom of this table.

Participant	Spatial Advantage Score (SD)					
	<i>Pre-Trial</i>	<i>Post-Trial</i>	<i>Follow-up</i>			
<i>Control Group</i>						
1	-1.19	-1.20	0.21			
4	-0.71	0	-0.97			
6	1.70	1.40	-0.41			
7	1.29	0.40	0.80			
8	0	0.70	0.82			
10	-1.66	-1.78	-0.99			
13	0.43	-2.20	0.61			
16	1.38	1.60	1.99			
18	-0.9	0.10	-0.09			
19	-0.02	-1.19	-0.94			
21	-1.51	-2.80	-3.58			
23	-1.10	-0.10	0.03			
<i>FM group</i>						
3	-3.02	-1.10	-1.39			
5	-2.75	-3.41	-2.29			
12	-2.11	-2.80	-3.94			
14	-2.20	-3.10	-2.00			
15	-2.01	0.40	0.97			
17	-2.28	-0.60	-0.70			
22	-2.45	-0.50	0.02			
24	-2.35	-1.60	-1.26			
	Low Cue Speech Recognition Threshold (S.D.)			High Cue Speech Recognition Threshold (S.D.)		
	<i>Pre-Trial</i>	<i>Post-Trial</i>	<i>Follow-up</i>	<i>Pre-Trial</i>	<i>Post-Trial</i>	<i>Follow-up</i>
2	-2.60	-1.30	-1.07	-4.20	-0.50	-1.46
9	-3.26	-0.30	-1.88	-2.83	-1.50	-0.52

3.2.1.1. Effects of FM System Use on Spatial Streaming Segregation Abilities

Results from two-way RM ANOVAs performed on the spatial advantage scores revealed a significant group effect, as shown below in Table 5. Post-hoc tests using the Holm-Sidak method revealed that the FM participants performed significantly more poorly than the control participants prior to the implementation of the FM devices. While this difference was still apparent at the post-trial and follow-up time points, the group data reflects the inclusion of those three participants in the FM group (Participants 5, 12 and 14) for whom no change occurred with FM stimulation. Inspection of the individual scores, shown in Table 4 (in Section 3.2.1), revealed that for those participants for whom an improvement was noted, their post-trial spatial advantage scores were well within the range of the control group. In the group data, there was nonetheless an improvement in the average spatial advantage score from the FM group such that there was no longer a significant difference between the FM and control groups at either the post-trial or follow-up time points (see Figure 6).

Table 5. Results of the two way RM ANOVAs for the spatial advantage, low cue SRT and high cue SRT scores from the control and FM groups (* Significant at 0.05 level; ** Significant at 0.005 level).

	N	Group	Sampling Point	Group x Sampling Point
Spatial Advantage	60	$F(1, 59) = 9.316, p = 0.007^*$	$F(2, 59) = 1.903, p = 0.164$	$F(2, 59) = 2.592, p = 0.089$
Low Cue SRT	42	$F(1, 41) = 7.810, p = 0.016^*$	$F(2, 41) = 2.894, p = 0.075$	$F(2, 41) = 0.482, p = 0.632$
High Cue SRT	42	$F(1, 41) = 2.837, p = 0.118$	$F(2, 41) = 8.363, p = 0.002^{**}$	$F(2, 41) = 5.809, p = 0.009^*$

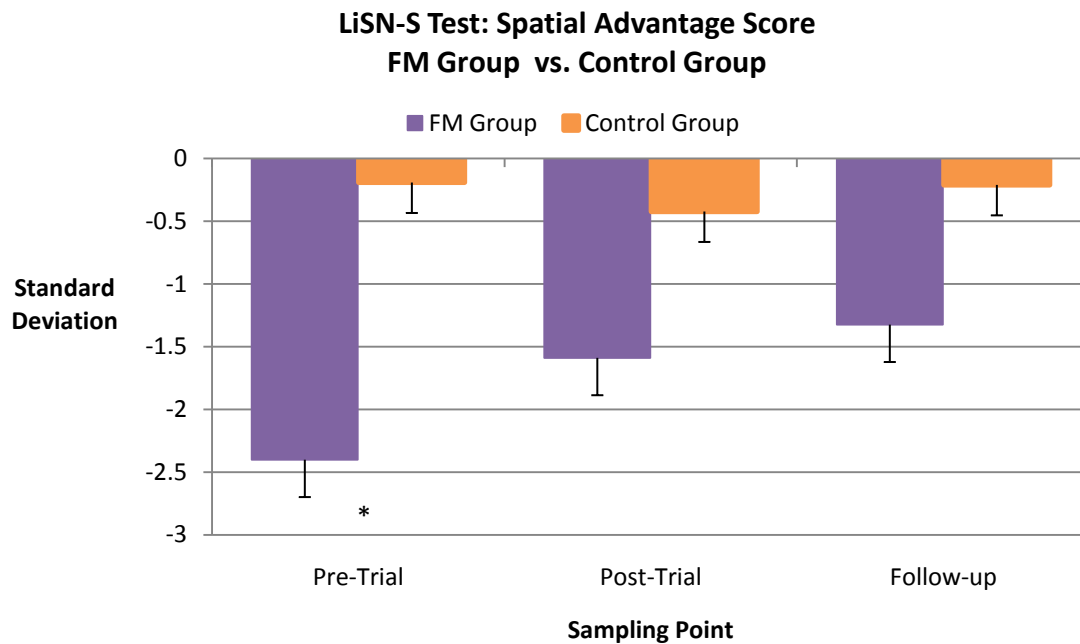


Figure 6. Comparisons between the means and standard errors of the means (SEMs) of the spatial advantage score (in SD) from the LiSN-S test for both the FM group (in purple; $n = 8$) and the control group (in orange; $n = 12$) across the three sampling points. (* Significant at 0.05 level).

3.2.1.2. Effects of FM System Use on Low Cue and High Cue SRTs

Two participants (i.e. participant 2 and 9) were included in the FM group based on their performances on the low cue and high cue speech recognition thresholds (SRTs) and these scores across the three sampling points are also listed at the bottom of Table 4 (see Section 3.2.1). In general, the control group's performances on both measures were within the normal limits (i.e. within 2 SD) across all three sampling points. The average performance of participants 2 and 9 (from the FM group) on both measures were outside the normal limits (i.e. outside 2 SD) prior to the FM trial only (see Figure 7 and Figure 8).

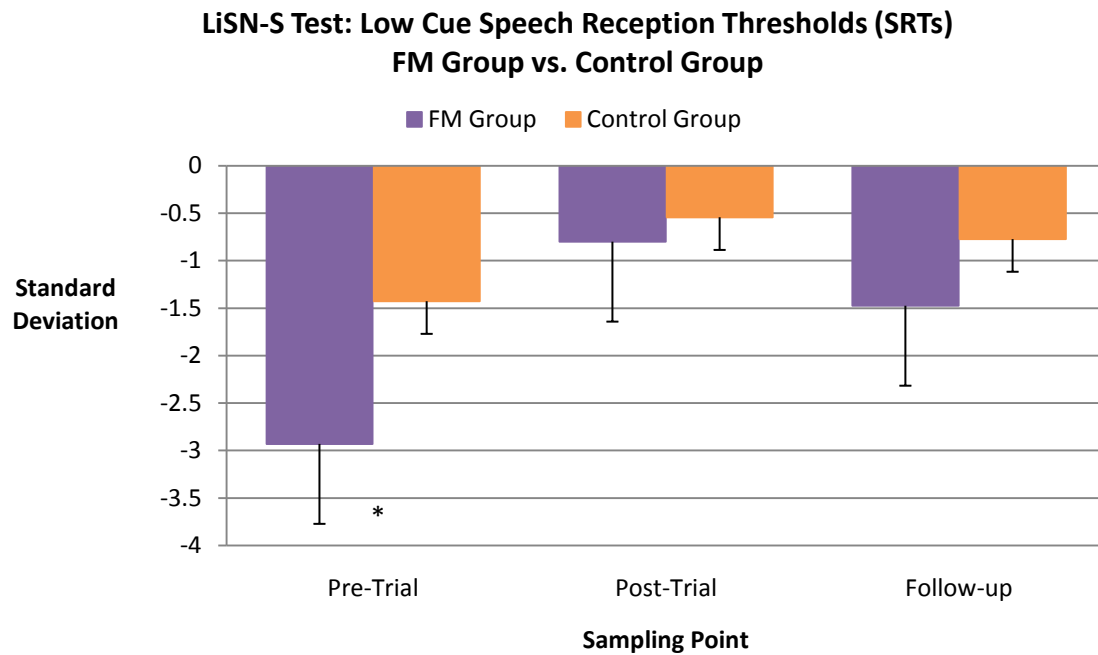


Figure 7. Comparisons of the means and standard errors of the means (SEMs) of the low cue SRTs (in SD) from the LiSN-S test obtained from the FM group (in purple; $n = 2$) and the control group (in orange; $n = 12$) (*Significant at 0.05 level).

For the low cue SRTs, results from two-way ANOVAs followed by post-hoc tests using the Holm-Sidak method revealed a significant group effect, as shown in Table 5 (see Section 3.2.1.1). As shown in Figure 7 above, the average low cue SRTs for the FM group were generally more negative than those of the control group, however, this difference was only significant at the pre-trial time point. The FM group demonstrated an improvement at the post-trial and follow-up time point, in which their average low cue SRTs shifted from being outside to being within the normal limits.

For high-cue SRTs, results from two-way ANOVAs revealed a significant sampling point effect and significant group-by-sampling point interaction effect (see Table 5 from Section 3.2.1.1). As shown in Figure 8, the average high cue SRT for the FM group shifted from being well outside normal limits (i.e. more than 2 SD below mean) at pre-trial, to being within normal limits (i.e. less than 2 SD from mean) at the post-trial and follow-up time points. For the control group, post-hoc tests using the Holm-Sidak method revealed that high cue SRTs were significantly smaller (i.e. more positive) at the follow-up session than at the post-trial session (shown in Figure 8), but was within normal limits across each time point.

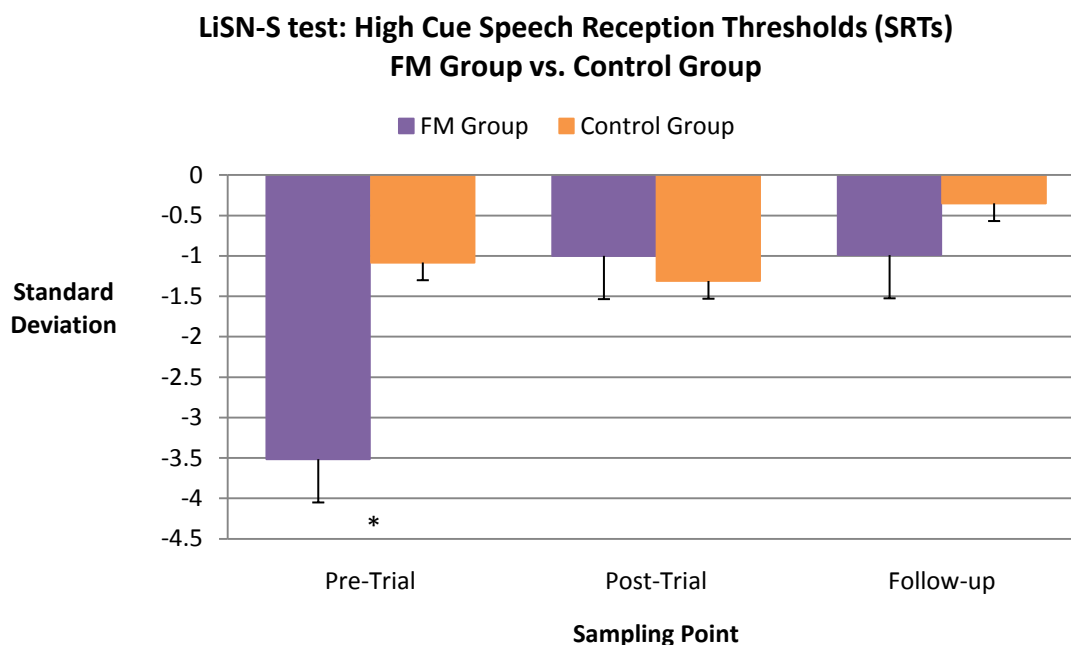


Figure 8. Comparisons between the means and standard errors of the means (SEMs) of the high cue speech reception thresholds (in SD) from the Listening in Spatialized Noise -Sentences (LiSN-S) test for the FM group (in purple; $n=2$) and the control group (in orange; $n=12$) across the three sampling points (*Significant at 0.05 level).

3.2.2. Effects of FM System Use on Reading and Comprehension Skills

Results from a series of two-way ANOVAs performed on three subtests from NEALE-3, as shown in Table 6, revealed no statistically significant group, sampling point or group-by-sampling point interaction effects. However, as displayed in Table 7, the statistical powers were very low. Although the FM group's reading and comprehension skills were worse than that of the control group (see Figure 9), their performance improved following eight weeks of FM stimulation (i.e. higher percentile rank at the post-trial time point compared to the pre-trial time point). Both groups performed poorly on the NEALE-3, with the average scores from all three subtests being below the 18th percentile. The average scores for two of the three subtests (i.e. reading accuracy and reading comprehension) were below the 10th percentile.

Table 6. Results of two-way RM ANOVAs performed on the percentile ranks obtained from the NEALE-3 for all participants. (*Significant at 0.05 level; ** Significant at 0.005 level).

	N	Group	Sampling Point	Group x Sampling Point
Reading Accuracy	44	$F(1, 43) = 0.781, p = 0.387$	$F(1, 43) = 0.0582, p = 0.812$	$F(1, 43) = 0.471, p = 0.500$
Reading Comprehension	44	$F(1, 43) = 2.447, p = 0.133$	$F(1, 43) = 0.209, p = 0.653$	$F(1, 43) = 2.385, p = 0.138$
Reading Rate	44	$F(1, 43) = 0.110, p = 0.743$	$F(1, 43) = 2.956, p = 0.101$	$F(1, 43) = 0.208, p = 0.653$

Table 7. Statistical power of performed test for (1) group, (2) sampling point; (3) group x sampling point from the two-way RM ANOVAs performed on the percentile ranks obtained from the NEALE-3 (alpha = 0.0500).

	Group	Sampling Point	Group x Sampling Point
Reading Accuracy	0.05	0.05	0.05
Reading Comprehension	0.197	0.05	0.19
Reading Rate	0.05	0.252	0.05

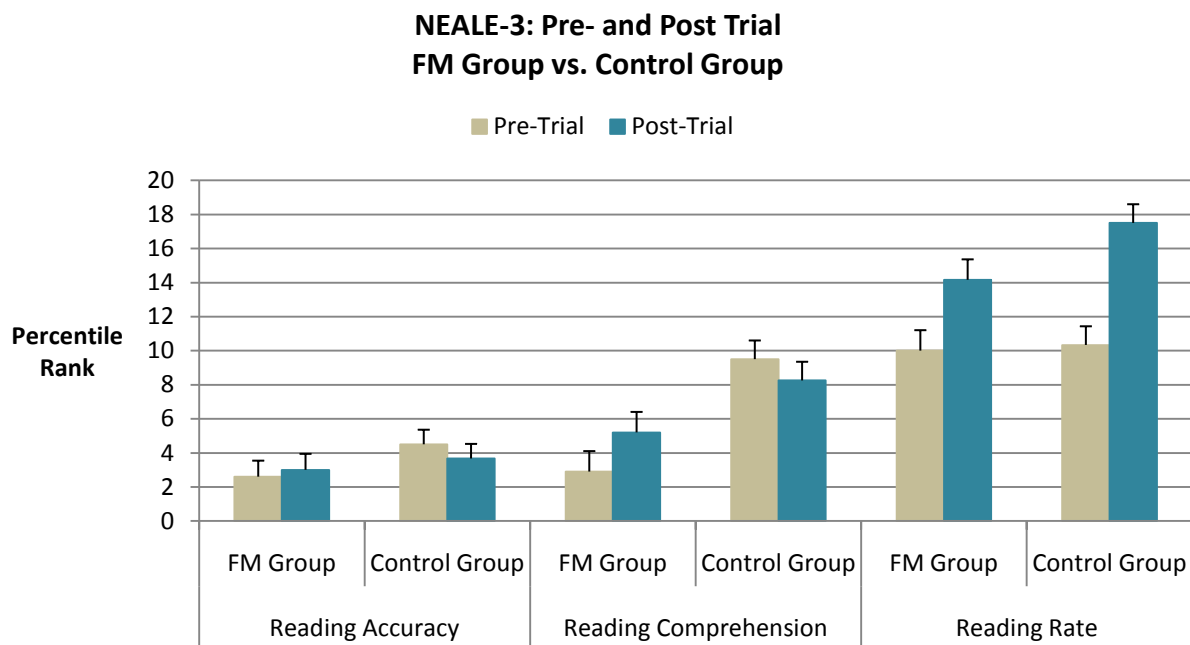


Figure 9. Comparisons between the pre- and post-trial performances of the FM group (n=10) and the control group (n=12) on the NEALE-3.

3.2.3. *Effects of FM System Use on Phonological Awareness Skills*

In general, participants from both groups demonstrated no statistically significant changes in most of their phonological awareness skills. Their performances, however, generally improved following the stimulation period. Further details regarding these results are discussed in the following sections.

3.2.3.1. *Effects of FM System Use on Phonological Awareness Skills as Measured by the QUIL*

Results from a series of two-way ANOVAs performed on four subtests from the QUIL are shown in Table 8. Although both groups appeared to have improved on their syllable segmentation skills after the FM trial, a significant sampling point effect was only found within the FM group and not within the control group. Syllable segmentation was a phonological skill that the participants were specifically taught in class during the FM trial. A significant group by sampling point effect was also noted, however, post-hoc tests using the Holm-Sidak method failed to reveal any significant difference in any of the comparison pairs. Although there seems to be a general trend where both groups performed better following the FM trial (see Figure 10), no statistically significant group, sampling point or group-by-sampling point interaction effects were found on any other subtests.

Table 8. Results of two-way RM ANOVAs performed on the standard scores obtained from the Queensland Inventory of Literacy for all participants. (* Significant at 0.05 level; ** Significant at 0.005 level).

	N	Group	Sampling Point	Group x Sampling Point
Non-word Spelling	44	$F(1, 43) = 0.00403, p = 0.950$	$F(1, 43) = 3.111, p = 0.093$	$F(1, 43) = 0.448, p = 0.511$
Syllable Identification	44	$F(1, 43) = 0.190, p = 0.668$	$F(1, 43) = 0.000927, p = 0.976$	$F(1, 43) = 5.785, p = 0.026^*$
Syllable Segmentation	44	$F(1, 43) = 0.996, p = 0.330$	$F(1, 43) = 10.626, p = 0.004^{**}$	$F(1, 43) = 0.409, p = 0.530$
Phoneme Segmentation	44	$F(1, 43) = 0.163, p = 0.691$	$F(1, 43) = 1.415, p = 0.248$	$F(1, 43) = 0.0617, p = 0.806$

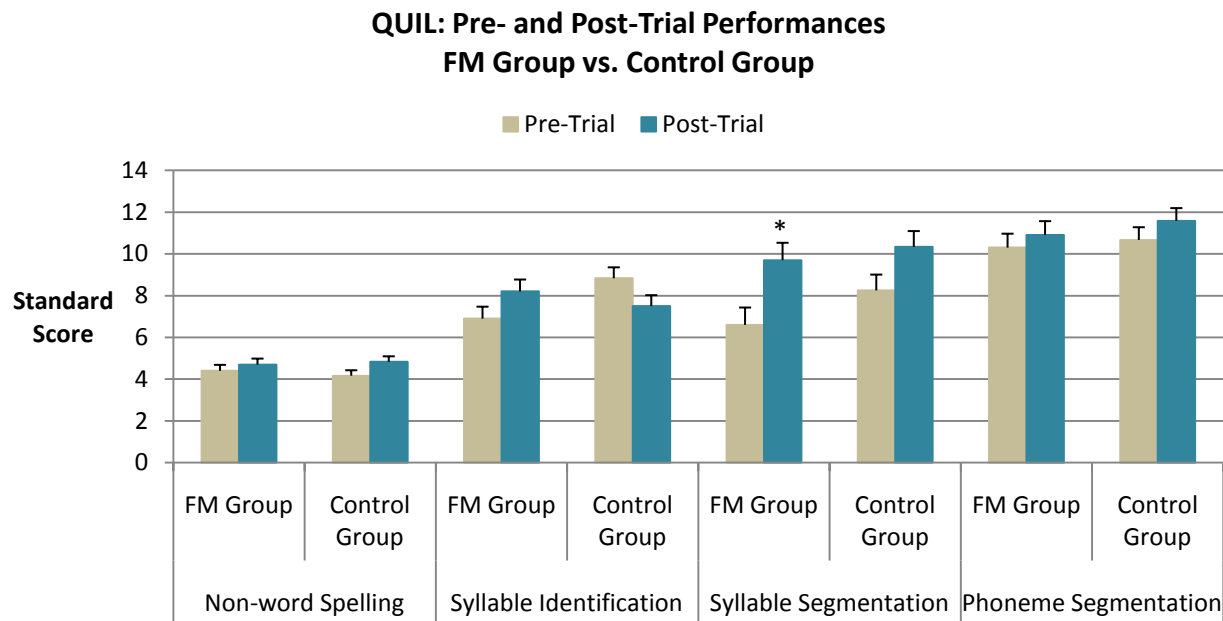


Figure 10. Comparisons between the pre- and post-trial performances of the FM group and control group on the subtests of the Queensland University Inventory of Literacy (QUIL) (* Significant at 0.05 level).

3.2.3.2. *Effects of FM System Use on Phonological Awareness Skills as Measured by the CTOPP*

As outlined in Section 2.2.3.4, the CTOPP was only administered to participants from the FM group. Their performances, in standard scores, before and after the FM trial were submitted to a series of one-way RM ANOVAs. Scores from the Rapid Digit Naming subtest failed normality and were subsequently submitted to the Friedman RM ANOVAs on Ranks. These results along with those from the one-way RM ANOVAs are shown in Table 9. No statistical significance was found on any of the subtests from CTOPP. However, there was a general trend where FM participants improved on their performances at the post-trial time point (see Figure 32 and Figure 33 in Appendix 12).

Table 9. Results of one-way RM ANOVAs performed on the pre- and post-trial standard scores obtained from all FM participants (n=10) on the four subtests from the Comprehensive Test of Phonological Processing (CTOPP). † indicates failure of the normality testing; the Friedman RM ANOVA on Ranks was used. (* Significant at 0.05 level; ** Significant at 0.005 level).

Subtest	N	Between Treatment		
<i>Room 1 and 2</i>				
Phonological Memory Composite	10	F (1, 9) = 4.175, p = 0.071		
Non-word Repetition	10	F (1, 9) = 0.369, p = 0.545		
Memory for Digits	10	F (1, 9) = 3.524, p = 0.093		
Rapid Naming Composite	10	F (1, 9) = 0.0957, p = 0.764		
Rapid Letter Naming	10	F (1, 9) = 0.0476, p = 0.832		
	N	df	Chi-square	P (exact)
Rapid Digit Naming [†]	10	1	0.667	0.754

3.3. Findings for Qualitative Assessments

All qualitative assessments were completed by the teachers from each classroom for the FM participants only. As described in Section 2.5, the statistical analyses of qualitative data consisted of two independent variables, namely “teacher” (two levels: teacher A x teacher B; or teacher C x teacher D) and “sampling point” (three levels: pre-trial x post-trial x follow-up). Teacher effect refers to the inter-rater differences in scoring. Sampling point effect simply refers to reported changes in relation to the FM trial period. The effect of the interaction between these two factors is referred to as the “teacher-by-sampling point” effect. In addition, descriptive statistics are provided for the GAS scores obtained post-trial. Results from a series of one-way and two-way ANOVAs performed on the Fisher’s Auditory Problems Checklist and the C.H.A.P.S., as well as the GAS scores are presented in the following sections.

3.3.1. Effects of FM System Use on C.H.A.P.S. Score

Averaged C.H.A.P.S. scores of -1 and above indicate auditory performance within the normal range. Conversely, scores below -1 (i.e. more negative) indicate auditory performance at risk of an auditory processing disorder. Results from a series of two-way RM ANOVAs performed on the average C.H.A.P.S. scores obtained separately from Room 1 and Room 2 are

presented in Table 10. A significant teacher effect was also found in the average C.H.A.P.S. scores in all conditions for Room 1, where Teacher A's ratings were consistently lower than Teacher B's ratings (i.e. Teacher A perceived the FM participants in her classroom as having more difficulty than did Teacher B; see Figure 11). Similarly, a teacher effect was found in the average condition scores in three listening conditions (i.e. Noise, Ideal and Multiple Inputs) for Room 2, where Teacher D's ratings was significantly lower than Teacher C's on two of the three conditions and vice versa for one of the three conditions (see Figure 11).

Table 10 also shows a significant sampling point effect in all but two conditions for Room 1 (Ideal and Auditory Memory Sequencing) and Room 2 (Auditory Memory Sequencing and Auditory Memory). Results from the post-hoc tests using the Holm-Sidak method for Room 1 and Room 2 are shown in Figure 34 and Figure 35 (from Appendix 13) respectively. In general, the C.H.A.P.S. scores were lowest at the follow-up time point, indicating poorer auditory processing skills. The highest C.H.A.P.S. scores were obtained at the post-trial and pre-trial time point, for Room 1 and Room 2 respectively.

A significant teacher-by-sampling point interaction effect was found in the "Quiet" condition in Room 1 and in all but the "Quiet" and "Ideal" conditions in Room 2 (see Table 10). Specifically, Post-hoc tests using the Holm-Sidak method revealed Teacher A and D gave significantly lower scores (i.e. rated auditory performance as poorer) than Teacher B and C respectively across all sampling points.

Table 10. Results of two-way RM ANOVAs performed on the averaged C.H.A.P.S. scores for the FM participants from Room 1 and Room 2 across the three sampling points reported by their teachers (two teachers per classroom with five FM participants each). (* Significant at 0.05 level; ** Significant at 0.005 level).

	N	Teacher	Sampling Point	Teacher x Sampling Point
<i>Room 1 (n=5)</i>				
Noise	30	F (1, 29) = 10.431, p = 0.032*	F (2, 29) = 5.874, p = 0.027*	F (2, 29) = 1.007, p = 0.407
Quiet	30	F (1, 29) = 47.335, p = 0.002**	F (2, 29) = 6.408, p = 0.021*	F (2, 29) = 10.338, p = 0.006*
Ideal	30	F (1, 29) = 122.604, p < 0.001**	F (2, 29) = 0.725, p = 0.514	F (2, 29) = 3.108, p = 0.100
Multiple Inputs	30	F (1, 29) = 21.876, p = 0.009*	F (2, 29) = 5.808, p = 0.028*	F (2, 29) = 0.875, p = 0.453
Auditory	30	F (1, 29) = 15.007, p = 0.018*	F (2, 29) = 0.989, p = 0.413	F (2, 29) = 0.0778, p = 0.926
Memory				
Sequencing				
Auditory	30	F (1, 29) = 12.709, p = 0.023*	F (2, 29) = 5.559, p = 0.031*	F (2, 29) = 2.217, p = 0.171
Attention Span				
Total	30	F (1, 29) = 45.058, p = 0.003**	F (2, 29) = 5.595, p = 0.030*	F (2, 29) = 3.909, p = 0.065
<i>Room 2 (n=5)</i>				
Noise	30	F (1, 29) = 9.510, p = 0.037*	F (2, 29) = 4.975, p = 0.039*	F (2, 29) = 4.584, p = 0.047*
Quiet	30	F (1, 29) = 7.180, p = 0.055	F (2, 29) = 6.618, p = 0.020*	F (2, 29) = 1.615, p = 0.258
Ideal	30	F (1, 29) = 38.642, p = 0.003**	F (2, 29) = 13.317, p = 0.003**	F (2, 29) = 3.518, p = 0.080
Multiple Inputs	30	F (1, 29) = 29.333, p = 0.006**	F (2, 29) = 5.765, p = 0.028*	F (2, 29) = 5.040, p = 0.038*
Auditory	30	F (1, 29) = 2.187, p = 0.213	F (2, 29) = 1.118, p = 0.373	F (2, 29) = 12.201, p = 0.004*
Memory				
Sequencing				
Auditory	30	F (1, 29) = 1.542, p = 0.282	F (2, 29) = 3.026, p = 0.105	F (2, 29) = 6.630, p = 0.020*
Attention Span				
Total	30	F (1, 29) = 0.702, p = 0.449	F (2, 29) = 5.418, p = 0.033*	F (2, 29) = 12.432, p = 0.004**

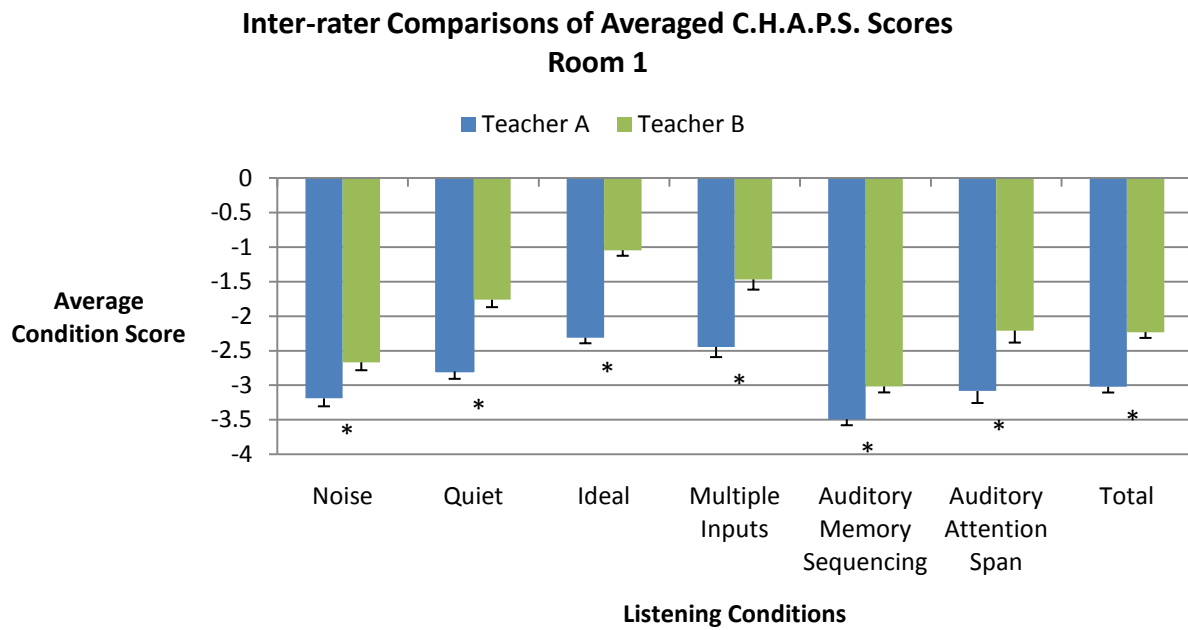


Figure 11. Inter-rater comparisons between the means and SEMs of the averaged C.H.A.P.S. scores reported by Teacher A (in blue) and Teacher B (in green) for the FM participants from Room 1 (n=5) on the seven listening conditions. (* Significant at 0.05 level).

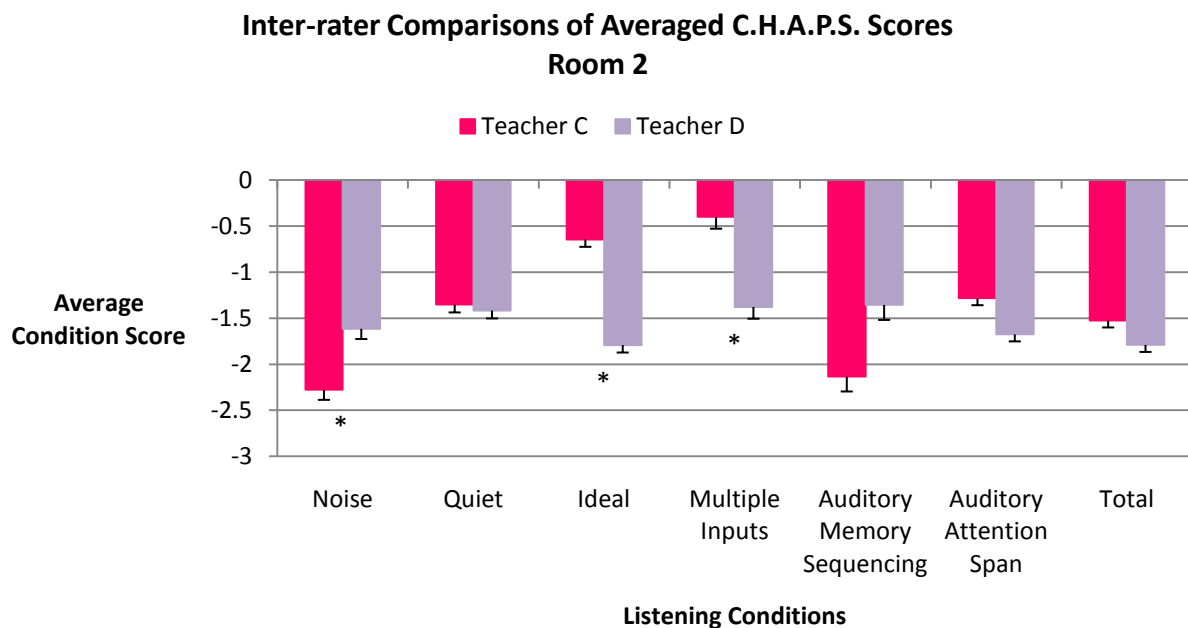


Figure 12. Inter-rater comparisons between the means and SEMs of the averaged C.H.A.P.S. scores reported by Teacher C (in pink) and Teacher D (in lavender) for the FM participants from Room 2 (n=5) for the seven listening conditions. (* Significant at 0.05 level).

The scores obtained from the two teachers for each classroom were then averaged and submitted to a series of one-way RM ANOVAs as one group (i.e. the FM group). Scores from the two conditions (i.e. “Ideal” and “Multiple Inputs”) which failed the normality test were subsequently submitted to the Friedman RM ANOVAs on Ranks. These results along with those from the one-way RM ANOVAs are shown in Table 11 below. A significant sampling point effect was found in all except the “Auditory Memory Sequencing” condition, where the teachers’ ratings were worst at the follow-up time point. Although not always statistically significant the teacher ratings were generally worse at the end of the FM-trial period compared to before the use of the FM system (see Figure 13).

Table 11. Results of one-way RM ANOVAs performed on the averaged condition scores from the C.H.A.P.S. for the FM group (n = 10) across the three sampling points. † indicates failure of the normality testing; the Friedman RM ANOVA on Ranks was used. (* Significant at 0.05 level; ** Significant at 0.005 level).

Condition	N	Between Treatment		
Noise	30	F (2, 29) = 5.138, p = 0.017*		
Quiet	30	F (2, 29) = 6.670, p = 0.007**		
Auditory Memory Sequencing	30	F (2, 29) = 1.223, p = 0.318		
Auditory Attention Span	30	F (2, 29) = 5.318, p = 0.015*		
Total	30	F (2, 29) = 5.255, p = 0.016*		
	N	df	Chi-square	p
Ideal†	30	2	9.947	0.007*
Multiple Inputs†	30	2	7.946	0.019*

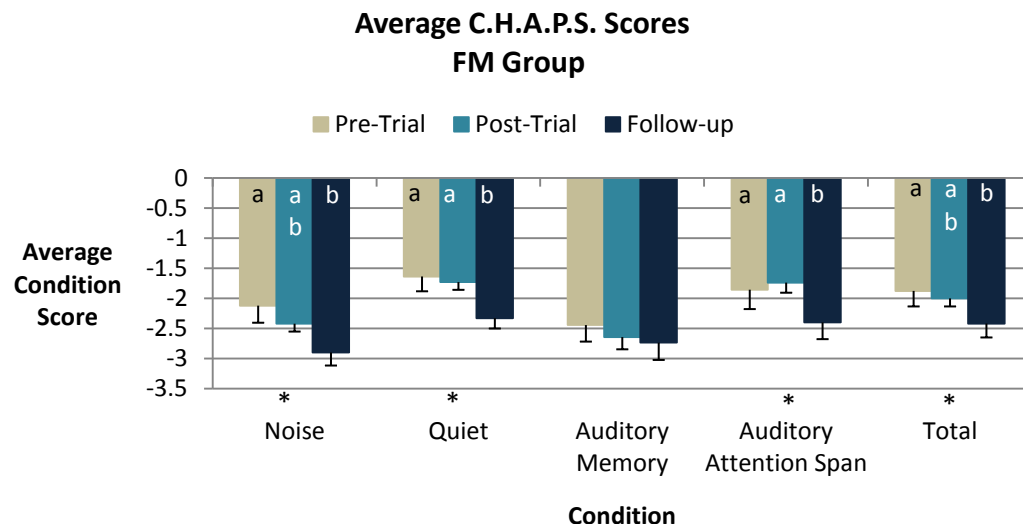


Figure 13. Comparisons between the means and standard errors of the average C.H.A.P.S. scores for the FM group (n=10) across the three sampling points. Results were based on the average of the individual scores, where scores obtained from two teachers per student were averaged. (Means that differ significantly are labelled with different letters; * Significant at 0.05 level).

3.3.2. *Effects of FM System Use on the Fisher's Auditory Problems Checklist Score*

Results from a series of two-way ANOVAs performed on the total percentage scores from the Fisher's Auditory Problems Checklist for the FM participants from Room 1 and Room 2 separately (i.e. two teachers per classroom) are presented in Table 12. A significant teacher effect and a significant teacher-by-sampling point effect were found in Room 1. Post-hoc tests using the Holm-Sidak method revealed a significant difference between Teacher A and Teacher B at pre- and post-trial as shown in Figure 14, where Teacher B generally rated the FM participants from Room 1 with higher scores (i.e. less behavioural manifestation of auditory processing problems) than Teacher A. No significant teacher and/or sampling point effects were found for Room 2 (see Figure 15). Percentage scores obtained from all four teachers followed a similar trend, where the results tended to peak at the post-trial sampling point.

Table 12. Results of two way RM ANOVAs for the percentage score obtained from the two classes (two teachers per classroom) on the Fisher's Auditory Problems Checklist for each FM participant. Room 1 and 2 consisted of younger and older students respectively (* Significant at 0.05 level; ** Significant at 0.005 level).

	N	Teacher	Sampling Point	Teacher x Sampling Point
Room 1	120	F (1, 29) = 7.812, p = 0.049*	F (2, 29) = 2.043, p = 0.192	F (2, 29) = 6.521, p = 0.021*
Room 2	120	F (1, 29) = 1.199, p = 0.335	F (2, 29) = 0.196, p = 0.826	F (2, 29) = 0.930, p = 0.433

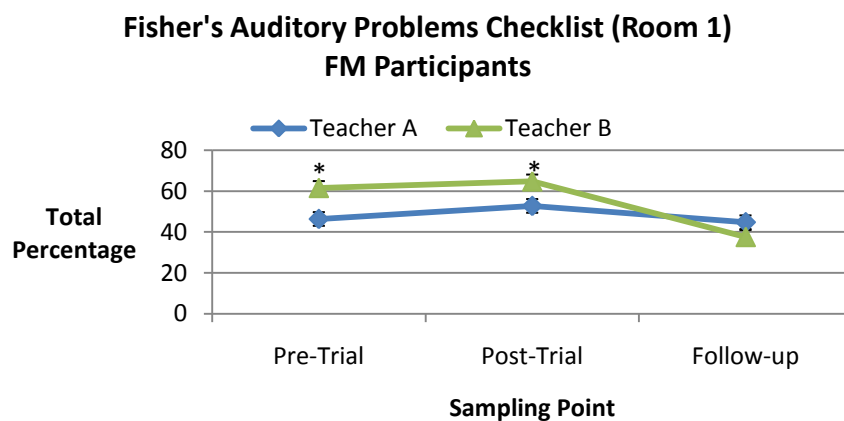


Figure 14. Comparisons between the means and standard errors of the total percentage score from the Fisher's Auditory Problems Checklist obtained from Teacher A (in blue) and Teacher B (in green) for the FM participants from Room 1 (n=5), across the three sampling points (*Significant at 0.05 level).

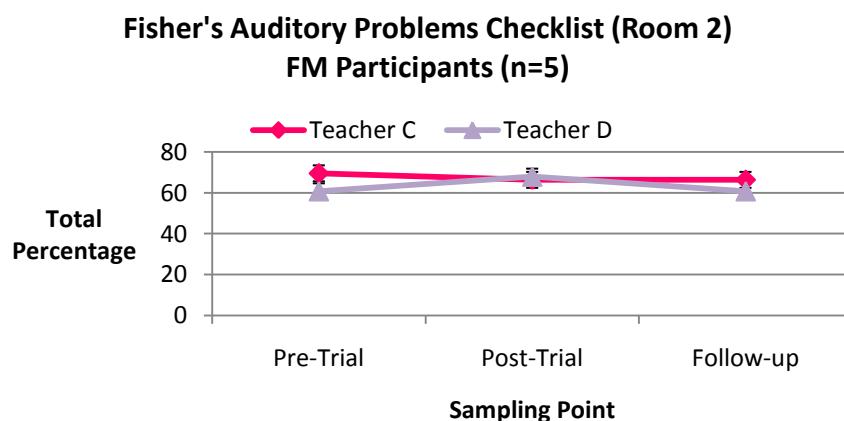


Figure 15. Comparisons between the means and standard errors of the means (SEM) of the total percentage score from the Fisher's Auditory Problems Checklist obtained from Teacher C (in pink) and Teacher D (in lavender) for the FM participants from Room 2 (n=5), across the three sampling points. (*Significant at 0.05 level).

The results from the two classrooms were further analyzed as one group, where the results from the two teachers from each classroom were averaged. A series of one-way ANOVAs were performed on these averaged scores to determine the changes across the different sampling points. The results are shown in Figure 16. No significant sampling points effect was found [$F(2, 29) = 2.061, p = 0.156$]. Overall, the results follow a pattern where the percentage score is highest (i.e. fewer behavioural problems associated with auditory processing) at the post-trial sampling point and the lowest at the follow-up period.

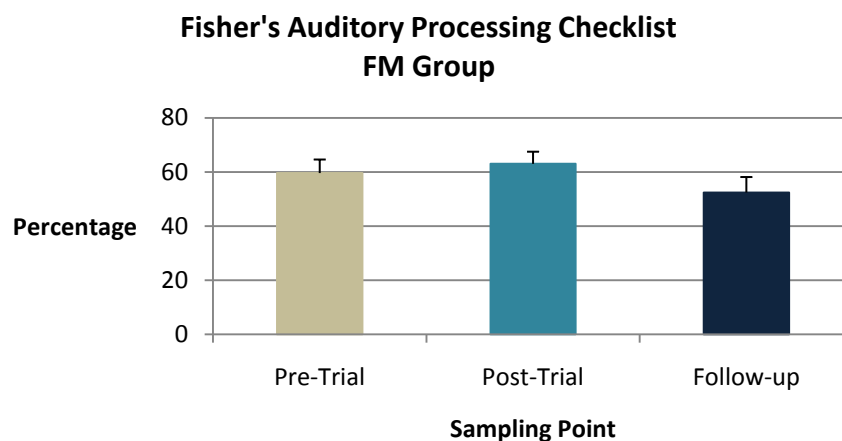


Figure 16. Comparisons between the means and standard errors of the means of the total percentage scores from the Fisher's Auditory Problems Checklist for the FM group ($n=10$) across the three sampling points. (* Significant at 0.05 level).

3.3.3. Effects of FM System Use on GAS Scores

Individual changes in attainment scores on each of the four GAS goals before and after the stimulation period for FM participants in Room 1 and 2 are presented in Figure 17 and Figure 18 respectively. As outlined in Section 2.2.4.3, achievement level 'slightly' and 'much' better than expected are represented by the score of '+1' and '+2' on a GAS respectively; while a score of '0' represents realistic/expected achievement level. Conversely, the GAS score of '-1' and '-2' represents achievement level 'slightly' worse than expected and no change in performance respectively. The summary GAS scores (i.e. sum of attainment scores across the four goals) for individual participant and as a group were converted to standardized T-scores using the formula from Kiresuk, Smith and Cardillo (Kiresuk, Smith, & Cardillo, 1994; see Table 13 in Appendix 14) and are shown in Figure 36 and Figure 37 in Appendix 14 respectively.

The teachers from Room 1 developed the criteria for all GAS goals collaboratively, and also chose to rate the participants' performance collaboratively. Thus, there was only one set of GAS scores reported for each FM participant from Room 1. Conversely, the teachers from Room 2 chose to rate the participants from their class individually. Consequently, two sets of GAS goals were reported for each FM participant from Room 2. Interestingly, their ratings were identical for all participants except for participant 3, where Teacher C reported the score of 0 for all 4 goals and Teacher D reported the scores of 2, 0, 2 and 2 for Goal 1 to 4 respectively. These results were averaged and are plotted in Figure 17.

In general, FM participants' abilities to (1) listen in competing speech; (2) follow verbal instructions; (3) listen for extended durations in a quiet environment; and (4) listen in the presence of background noise improved following the 8-week FM stimulation period. There was a general trend toward a peak in improvement in the participants' abilities to listen for extended durations in quiet (Goal 3) and to listen in the presence of background noise (Goal 4). This trend appears to be more robust for Room 2 participants (Goal 3 and 4: $M = 1.4$, $SD = 0.89$) than those in Room 1 (Goal 3: $M = 0.4$, $SD = 1.67$; Goal 4: $M = 0.6$, $SD = 1.34$). Only two out of the ten FM participants demonstrates GAS T-scores below 50, and they were both from Room 1. As a group, Room 2 yielded a higher T-Score (i.e. more improvement) with less variance than Room 1. However, the overall T-Score for the FM group as a whole (see Figure 37 in Appendix 14) suggested an improvement on their auditory behaviours following eight weeks of FM stimulation ($M = 58.71$, $SD = 5.13$).

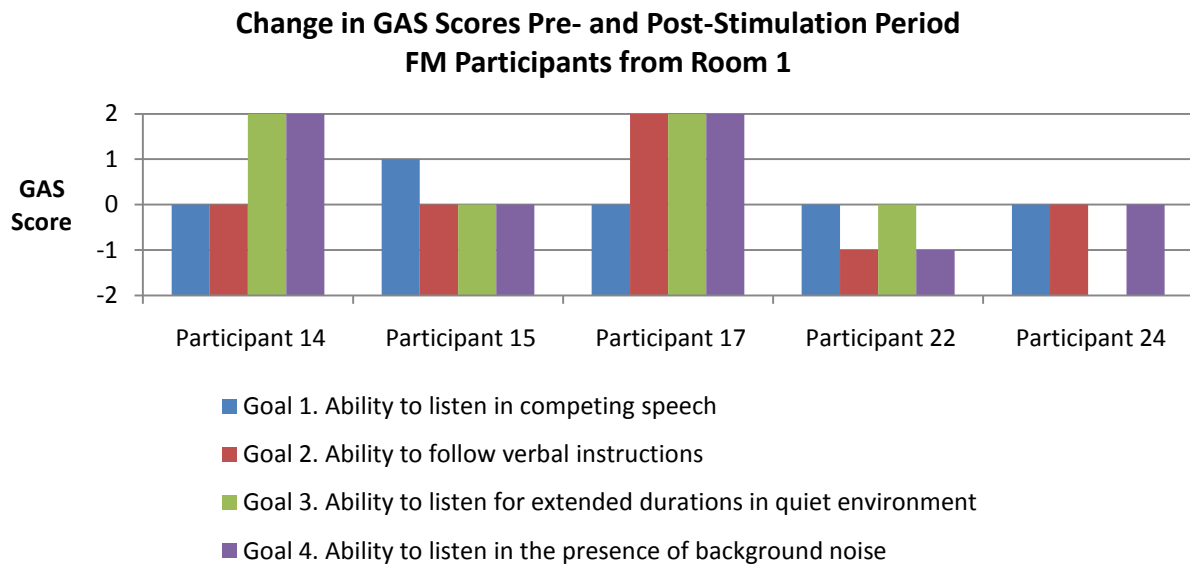


Figure 17. Average change in goal attainment scaling (GAS) scores pre- and post-stimulation period for FM participants from Room 1 (n=5).

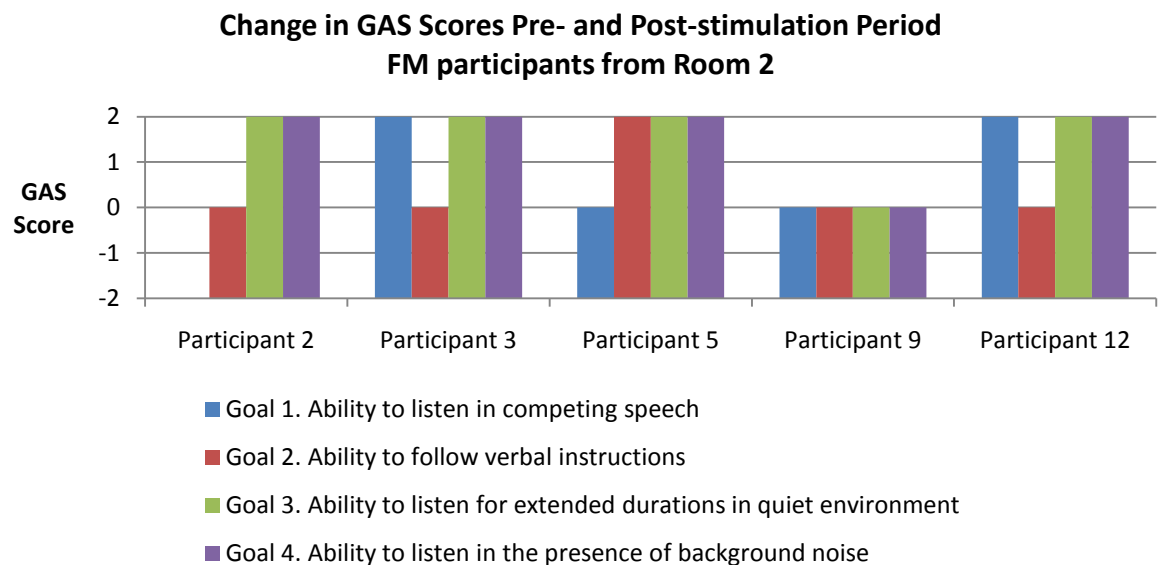


Figure 18. Average change in goal attainment scaling (GAS) scores pre- and post-stimulation period for FM participants from Room 2 (n=5).

3.4. Student Feedback

Results from the post-trial questionnaire for the FM group are shown in Figure 19 to Figure 22. The majority of participants (n = 8) rated the FM devices as between “ok” and “very easy” to handle; while the remainder were not required to handle the equipment at all (see

Figure 19). With regards to cleaning and maintenance of the devices, a small percentage of participants thought it was “very tricky” or “tricky”, but the majority (n=7) were not given the responsibility of caring for the devices (see Figure 19). In addition, all but one participant rated the device as between “ok” and “very comfortable” to wear (see Figure 20). The ratings on the post-trial student questionnaire, as shown in Figure 21, further indicated that the FM devices were perceived as being the most beneficial in quiet situations, during story time, and in noisy situations. Overall, the participants’ views of the FM devices with regards to its usefulness were generally positive (see Figure 22).

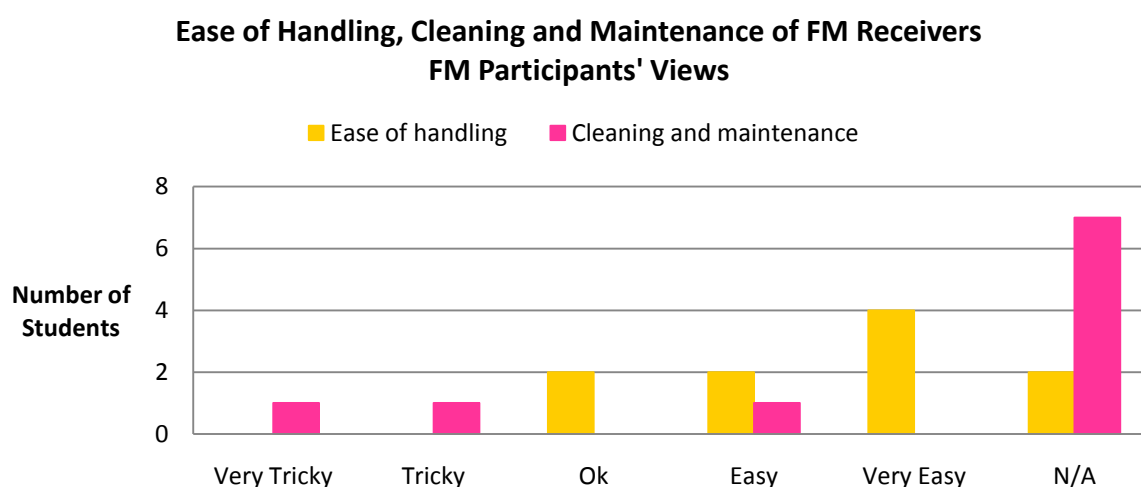


Figure 19. Feedback from the FM participants (n=10) on the ease of handling, cleaning and maintenance of the FM devices.

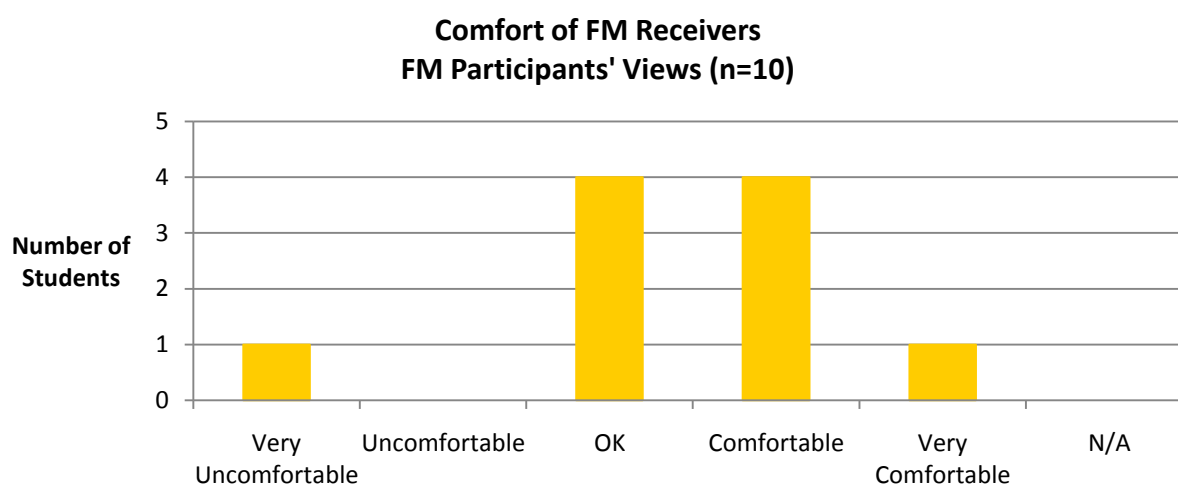


Figure 20. Feedback from the FM participants (n=10) on the comfort of the FM devices.

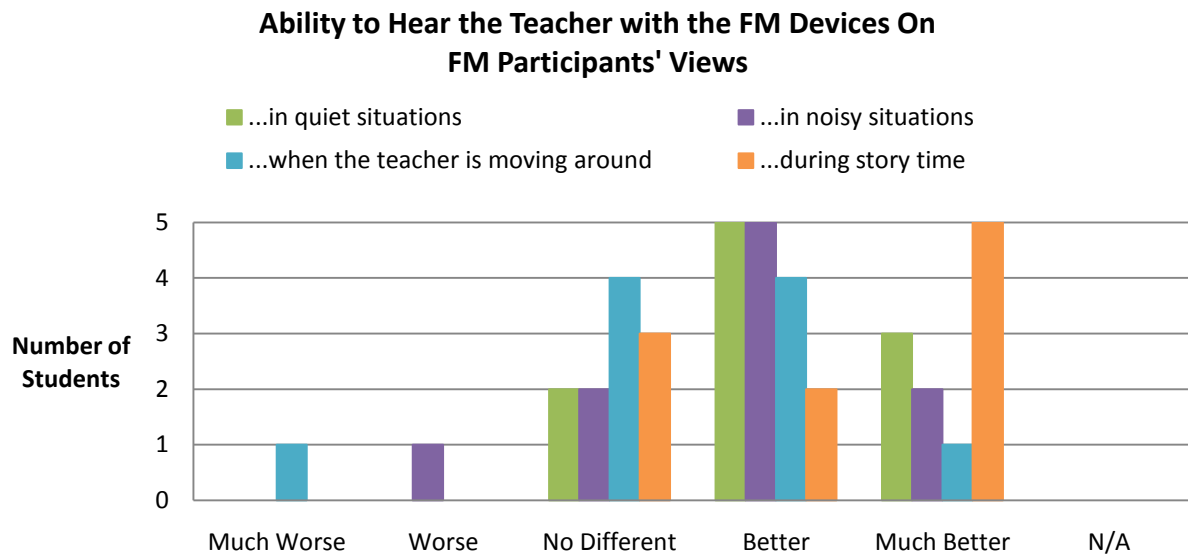


Figure 21. Feedback from the FM participants (n=10) on their ability to hear the teacher (1) in quiet situations; (2) in noisy situations; (3) when the teacher is moving around; and (4) during story time, while wearing the FM device switched on.

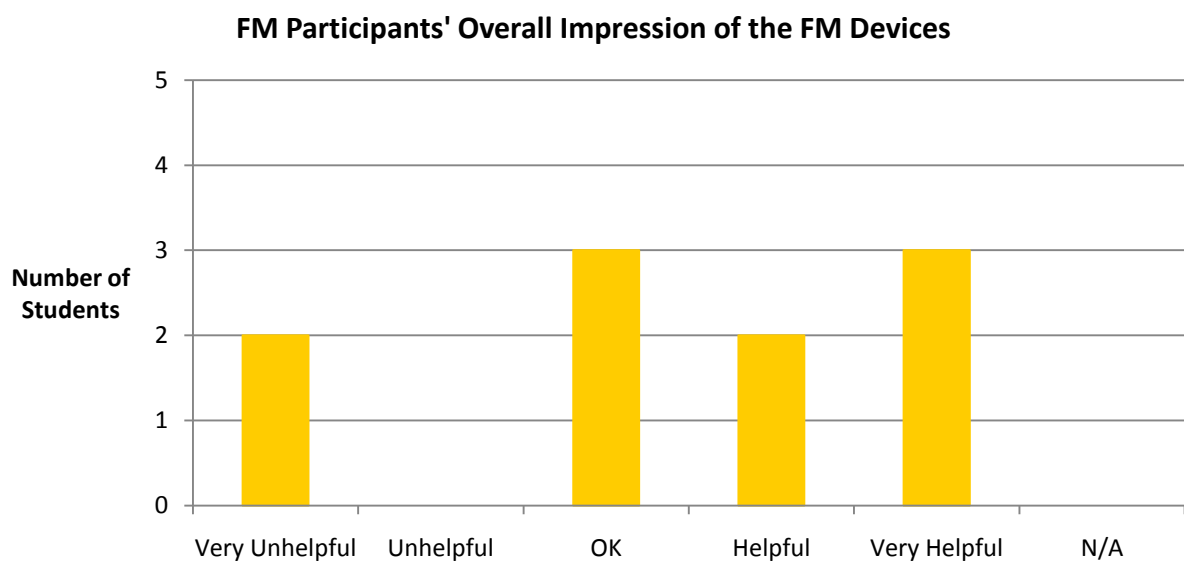


Figure 22. Feedback from the FM participants (n=10) on their overall impression of the FM devices.

3.5. *Summary of Main Findings*

The main findings from this study are as follows:

1. An 8-week period of auditory stimulation via a personal FM device resulted in improved speech perception in noise (due to better use of spatial cues) for the majority of participants, and improved auditory processing behaviours for all participants (that is, higher GAS scores, higher percentage from Fisher's Auditory Problems Checklist). These changes were consistent with the students' own feedback on their FM devices, as the majority of the group felt their device was beneficial for listening in most situations. The improvement in their spatial stream segregation skills was maintained even when the FM devices were no longer used. However, these changes were not directly reflected in the follow-up teacher ratings, in which they perceived the children's auditory behaviours to be worse than they were at baseline.
2. An inter-rater difference was found, for both classrooms, in most of the subcategories in the C.H.A.P.S. questionnaire; and for Room 1 in the Fisher's Auditory Problems Checklist. In general, the inter-rater difference was consistent throughout both questionnaires, where the teacher who rated the children more harshly on the C.H.A.P.S. also rated more harshly on the Fisher's Auditory Problems Checklist.
3. Following an 8-week period of FM usage, FM participants demonstrated noticeable improvements across the four listening GAS goals with individually-set criteria based on their abilities prior to the FM trial. The FM participants demonstrated most improvements in their ability to listen for extended durations in quiet (Goal 3) and to listen in the presence of background noise (Goal 4). This trend was particularly apparent for the older participants in Room 2.
4. While there was a small but insignificant improvement on the post-trial scores from the Fisher's Auditory Problems Checklist, the C.H.A.P.S. scores obtained across the three time points indicated that the teachers perceived a decline in the FM participants' auditory behaviours.
5. Following an 8-week period of FM use, participants in neither the control nor the FM group demonstrated improvements in phonological awareness skills, phonological memory, rapid

naming or literacy skills other than syllable segmentation, which was specifically taught in class during the trial period.

3.6. Case Studies

The participants described in the following four case studies all belonged to the FM group. Case 1 is one of the three participants who did not improve in his spatial stream segregation skills despite having 8 weeks of FM stimulation. Case 2, 3, and 4 are children who demonstrated improvements in their spatial stream segregation skills with varying success in their literacy and phonological awareness skills. What makes these cases interesting are the anecdotal comments reported by their teachers and the participants themselves. It is also worth noting that all participants in this study had learning difficulties, thus received daily teacher-aide support and weekly speech and language therapy and occupational therapy as part of their curriculum at this school.

3.6.1. Case 1 - Participant 14

Participant 14 was a male aged 8 years 8 months who presented with dyspraxia, dyslexia and mild autism. He had significant reading and spelling difficulties and a history of chronic OME. His mother reported that he had had more than 10 ear infections since birth, which were not treated with ventilation tubes. His mother also noted that her son was sensitive to loud sounds, often responded inappropriately to questions, and had difficulty following 2-step instructions. His teachers reported that he would often “daydream” and was easily distracted by background noise. He also reportedly had a short attention span and often required clarifications. His mother reported that he required oxygen shortly after birth, with an Apgar score of 4. His mother further reported that he did not start talking until the age of 4 and the development of both his expressive and receptive language was delayed.

At baseline assessment, he presented with bilateral type B tympanograms (consistent with OME) and was promptly referred to an otolaryngologist, who treated him with ventilation tubes bilaterally. Figure 23 and Figure 24 show his performance on objective and qualitative measures respectively. He was one of three FM participants whose spatial advantage score actually worsened following 8 weeks of FM stimulation. This correlates with the reduction in his teachers’ ratings on the Fisher’s Auditory Problems Checklist (lower scores represent more behavioural problems associated with weak auditory processing skills) and the C.H.A.P.S.

(negative scores indicate weaker auditory processing skills compared to his age-matched peers with normal auditory processing skills). One of his teacher noted that he “resisted” the use of the FM devices and felt that he “prefers to tune out regardless of [whether he was wearing the] FM [systems or not]”. In contrast, he reported that he found the FM devices to be “very comfortable” to wear and that he was able to hear his teachers “much better” in all situations. His self-reported feedback seems to correlate with his teachers’ ratings on the GAS goals, which were individualised goals with small but specific and achievable criteria. He also demonstrated improvements on most of the phonological awareness and literacy measures.

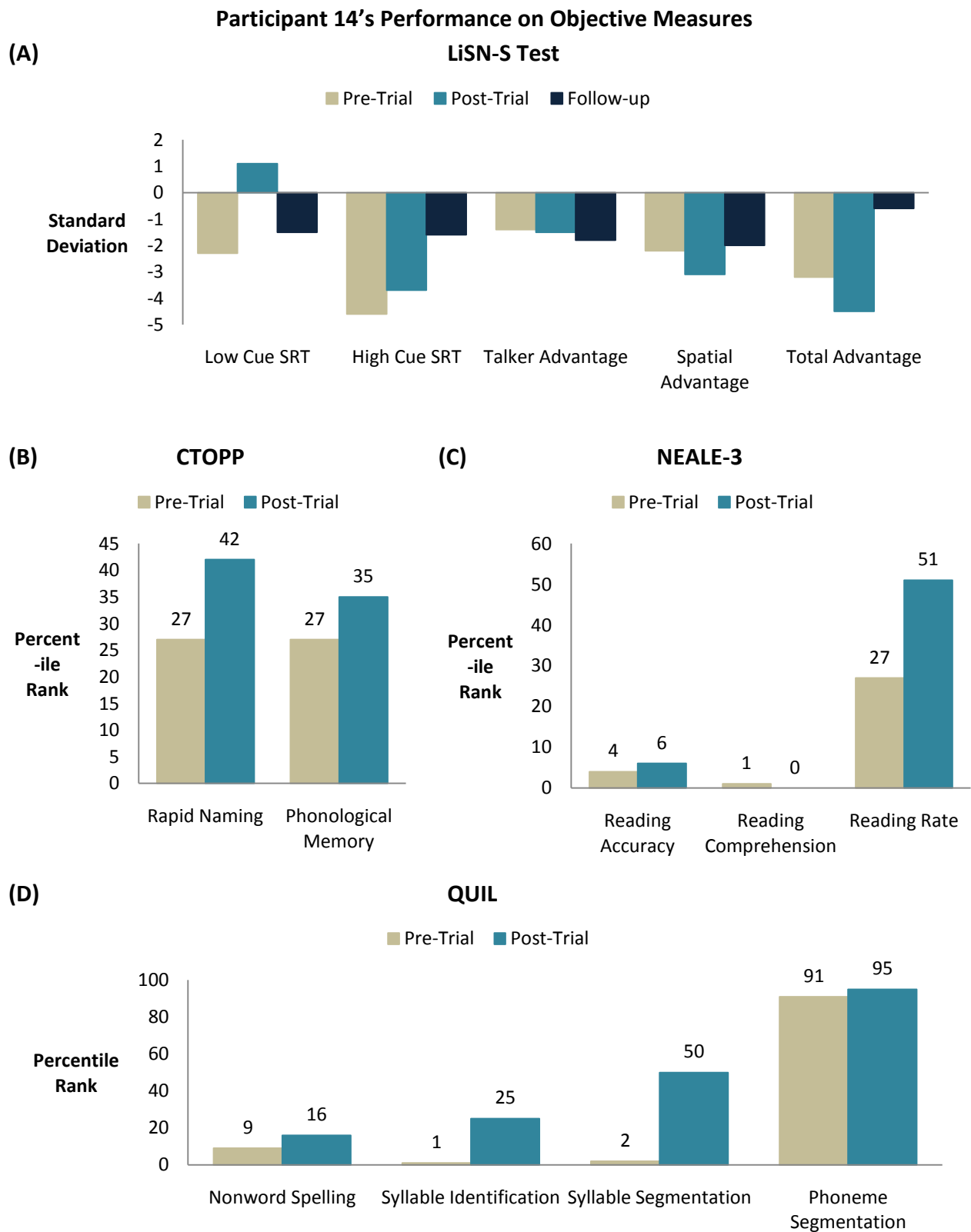


Figure 23. Participant 14's performance on the (A) LiSN-S test before, immediately after, and eight weeks following stimulation; and his performance on the (B) CTOPP, (C) NEALE-3 and (D) the QUIL before and after stimulation.

**Participant 14's Performance on the GAS, Fisher's Auditory Problems Checklist
and C.H.A.P.S. Scores**

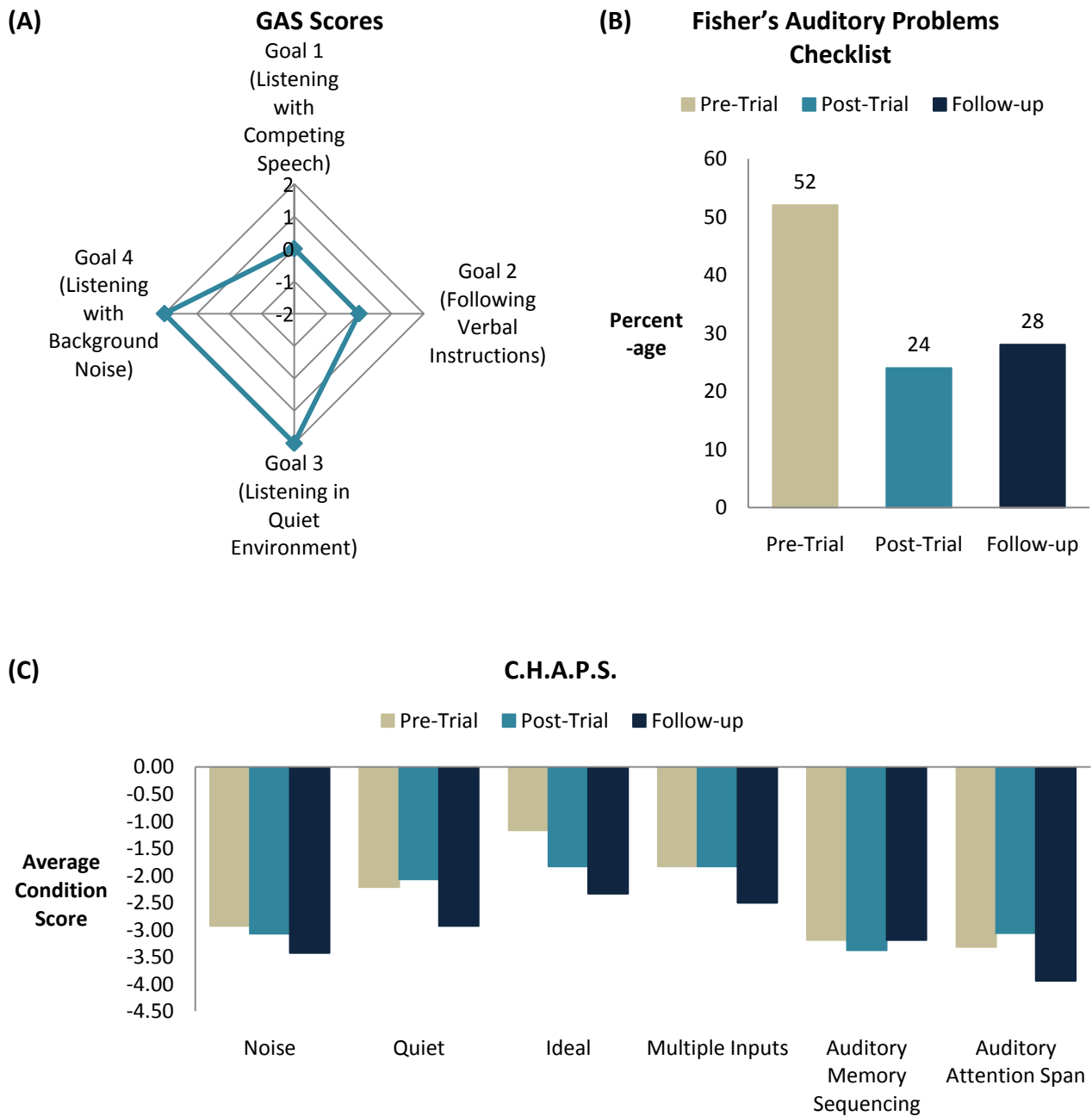


Figure 24. Changes in Participant 14's (A) GAS scores pre- and post-stimulation period; (B) total percentage score from the Fisher's Auditory Problems Checklist across the three sampling points; and (C) average scores on the six conditions from the C.H.A.P.S. across the three sampling points.

3.6.2. Case 2 - Participant 15

Participant 15 was a male aged 9 years 7 months who presented with severe dyspraxia and sensory processing disorder. He had difficulty understanding and following instructions in noisy situations, despite having normal peripheral hearing. He reportedly has had minimal ear infections as a child. His teachers reported that he frequently expressed his frustration with his noisy peers and was constantly telling them to 'shush'. His mother reported that he was born via emergency caesarean section with forceps and was diagnosed with a small hole in his heart at 3 months of age. His mother further reported that he began talking in 1- to 2-word phrases at around 3 years of age and the main concern was that his receptive language and literacy (i.e. reading and writing) were delayed. He also had some difficulty articulating words with more complex phonemic structures.

His performances on objective and qualitative measures are shown in Figure 25 and Figure 26 respectively. In general, his improvement on the spatial stream segregation skills appears to be independent of the development of his literacy skills. He thought the FM system was "cool" and he enjoyed wearing the device for as long as possible. Interestingly, he reported that he found the FM devices "ok" (i.e. neither helpful or unhelpful), but when asked to complete the following sentence "When I was wearing the FM devices and other students were making noise/the teacher is moving around, I can hear the teacher... than when I was not wearing the FM devices" (see Appendix 11) he responded that the FM devices allowed him to hear his teacher "better", regardless of whether his teacher was stationary or moving around the classroom, during both quiet and noisy situations. This was reflected in his teachers' ratings on the GAS goals, the Fisher's Auditory Problems Checklist, and the C.H.A.P.S., where his teachers felt that his auditory processing skills improved following eight weeks of FM stimulation, especially in noisy environments where competing speech was present (see Figure 26). The teachers also noted that he reduced the number of times he had asked his peers to be quiet during the FM trial; however, this behaviour worsened significantly during the follow-up period where the FM systems were no longer in use.

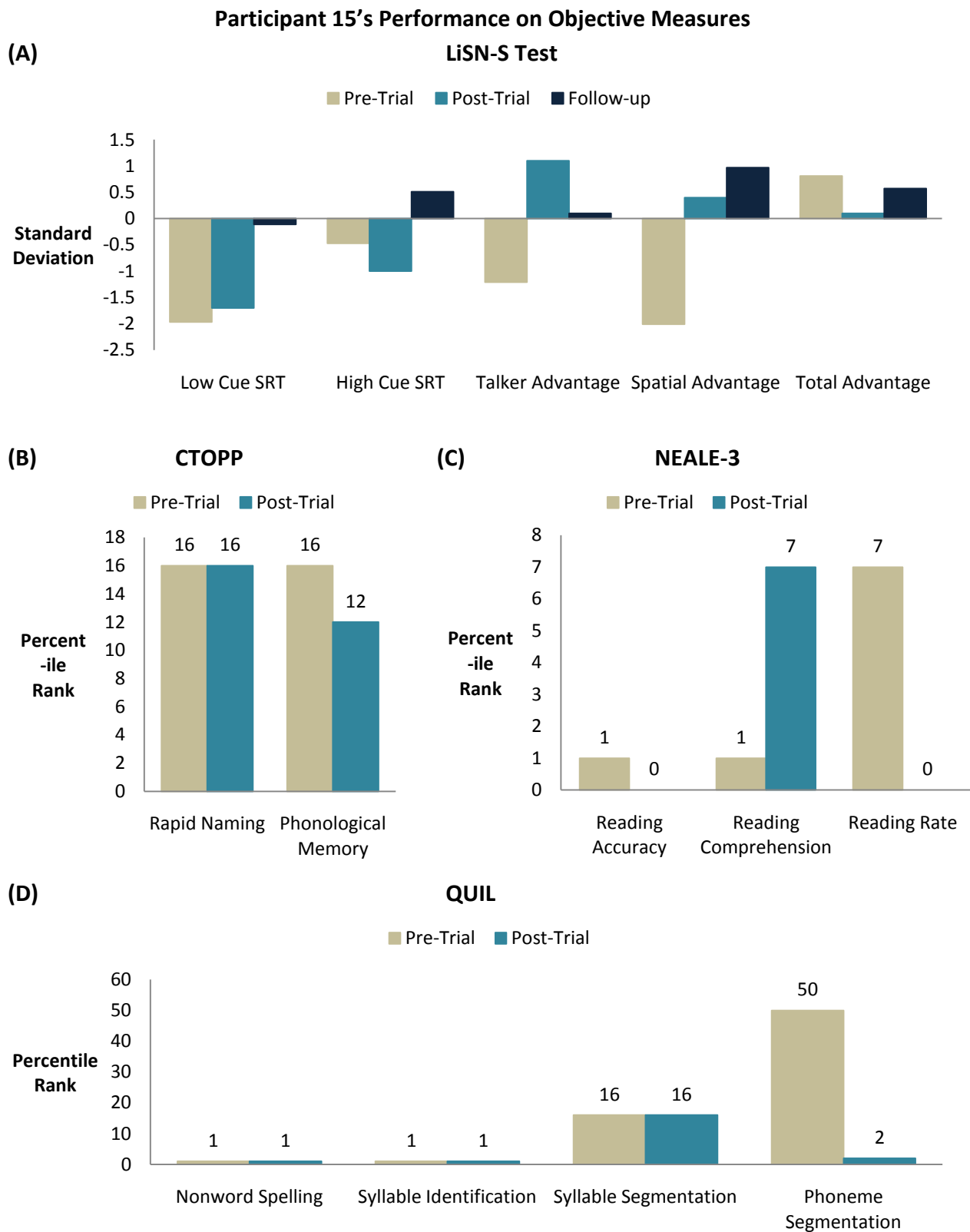


Figure 25. Participant 15's performance on the (A) LiSN-S test before, immediately after, and eight weeks following stimulation; and his performance on the (B) CTOPP, (C) NEALE-3 and (D) the QUIL before and after stimulation.

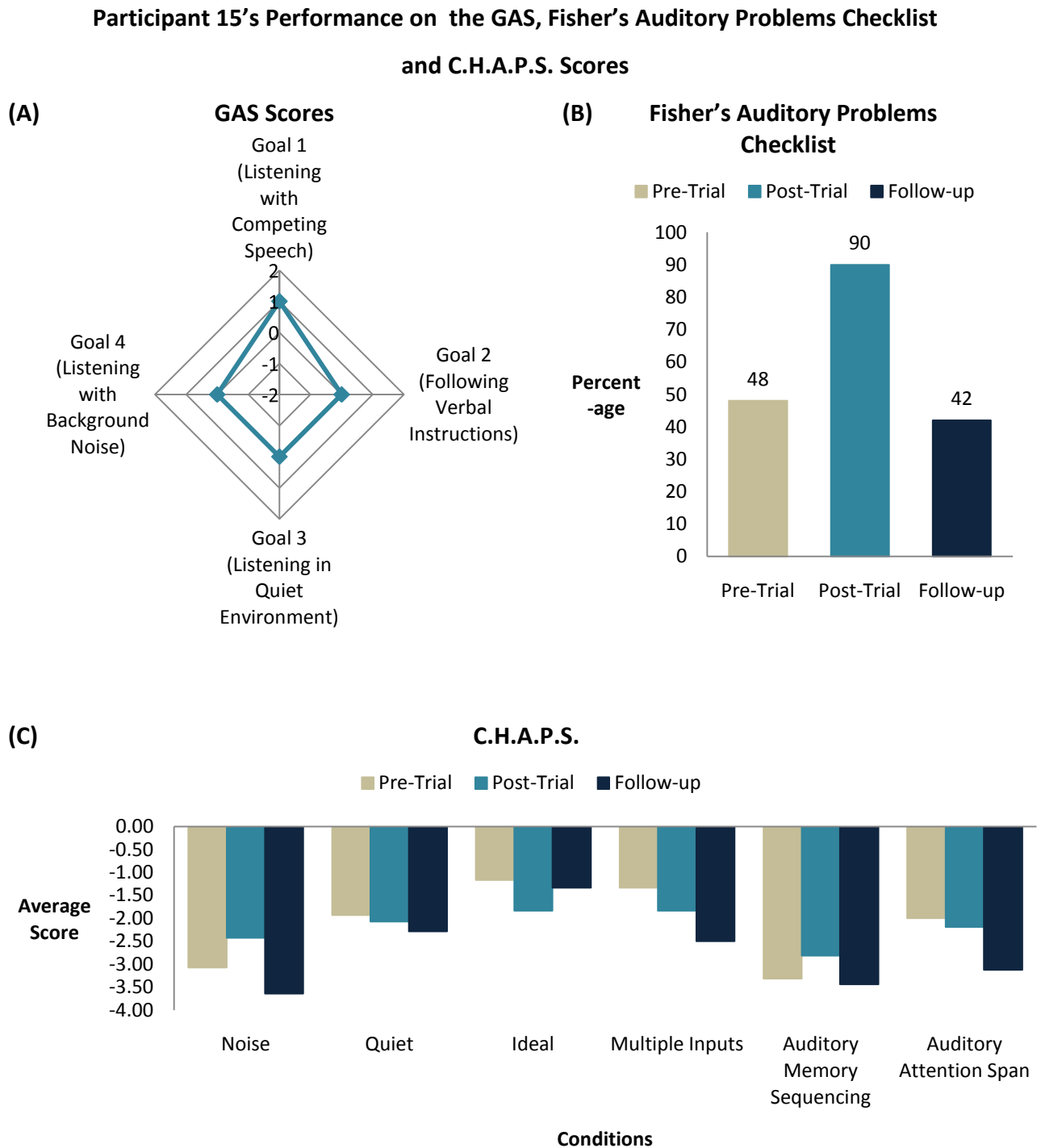


Figure 26. Changes in Participant 15's (A) GAS scores pre- and post-stimulation period; (B) total percentage score from the Fisher's Auditory Problems Checklist across the three sampling points; and (C) average scores on the six conditions from the C.H.A.P.S. across the three sampling points.

3.6.3. Case 3 - Participant 22

Participant 22 was a male aged 9 years 7 months who presented with dyspraxia. He had difficulty staying on task, remembering what was said to him and following instructions and understanding (especially sarcasm and humour). It was noted that his voice was often monotonic and he was easily distracted in noisy situations. No significant family history of hearing difficulties was reported, however, he did have three to five ear infections as a preschooler. His mother reported that one of his older male cousins had a learning disability. She further reported that he had difficulty writing (e.g. reversing numbers and letters).

His performances on objective and qualitative measures are shown in Figure 27 and Figure 28 respectively. He improved on the spatial advantage score post-stimulation and maintained the improvement even at the follow-up session. It is particularly interesting that he reported that he was able to hear the teacher “better” in all but during story time, where he felt the FM systems made “no difference” to his ability to hear the teacher. His teachers’ reported the opposite finding, where they felt his auditory behaviours improved the most during quiet environments such as story time, as indicated by the GAS scores (see Figure 28). Interestingly, he was one of the three participants who had the lowest total GAS score. Following the withdrawal of the FM systems, he had reportedly asked for his “ears” back (i.e. the FM systems).

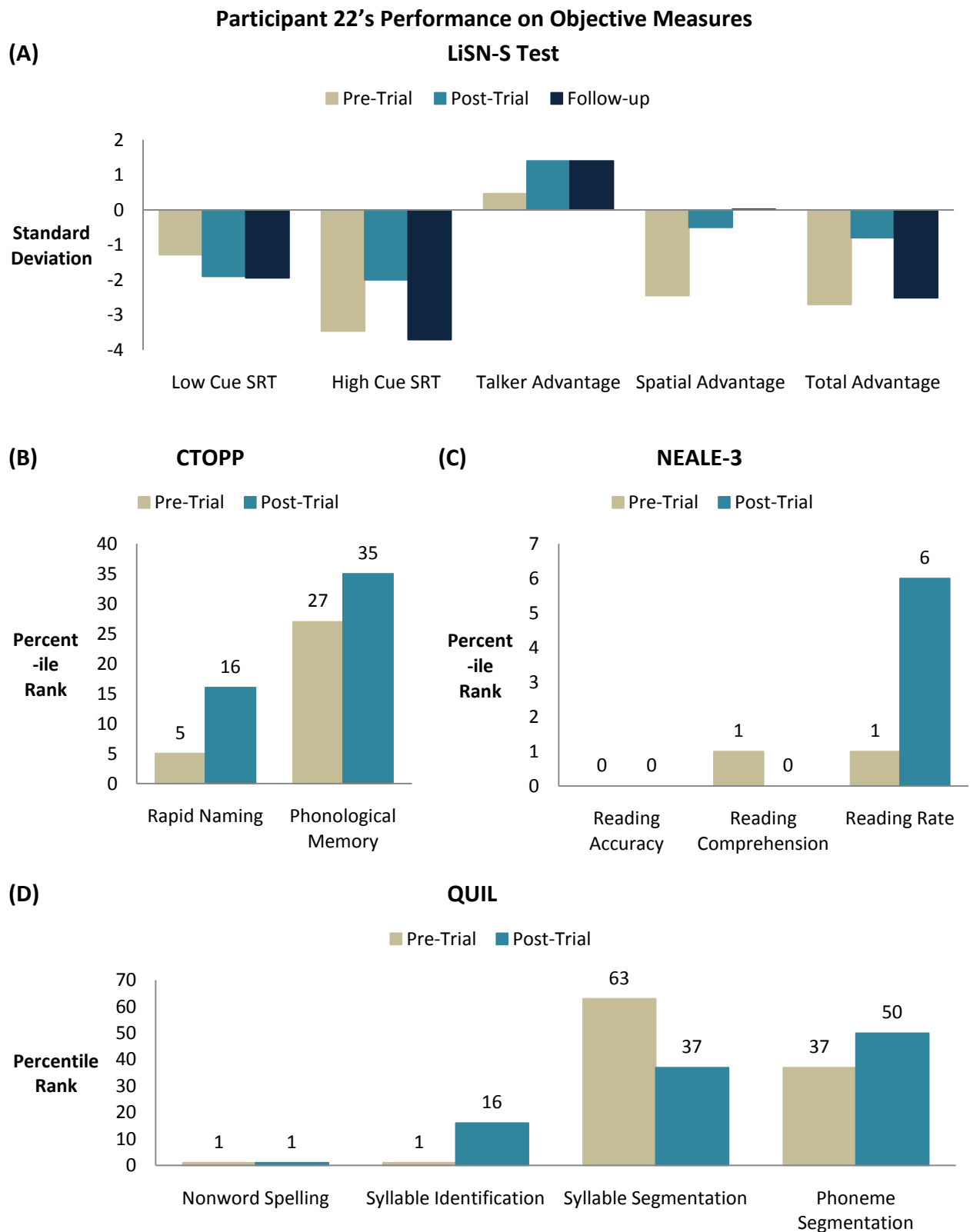


Figure 27. Participant 22's performance on the (A) LiSN-S test before, immediately after, and eight weeks following stimulation; and his performance on the (B) CTOPP, (C) NEALE-3 and (D) the QUIL before and after stimulation.

**Participant 22's Performance on the GAS, Fisher's Auditory Problems Checklist
and C.H.A.P.S. Scores**

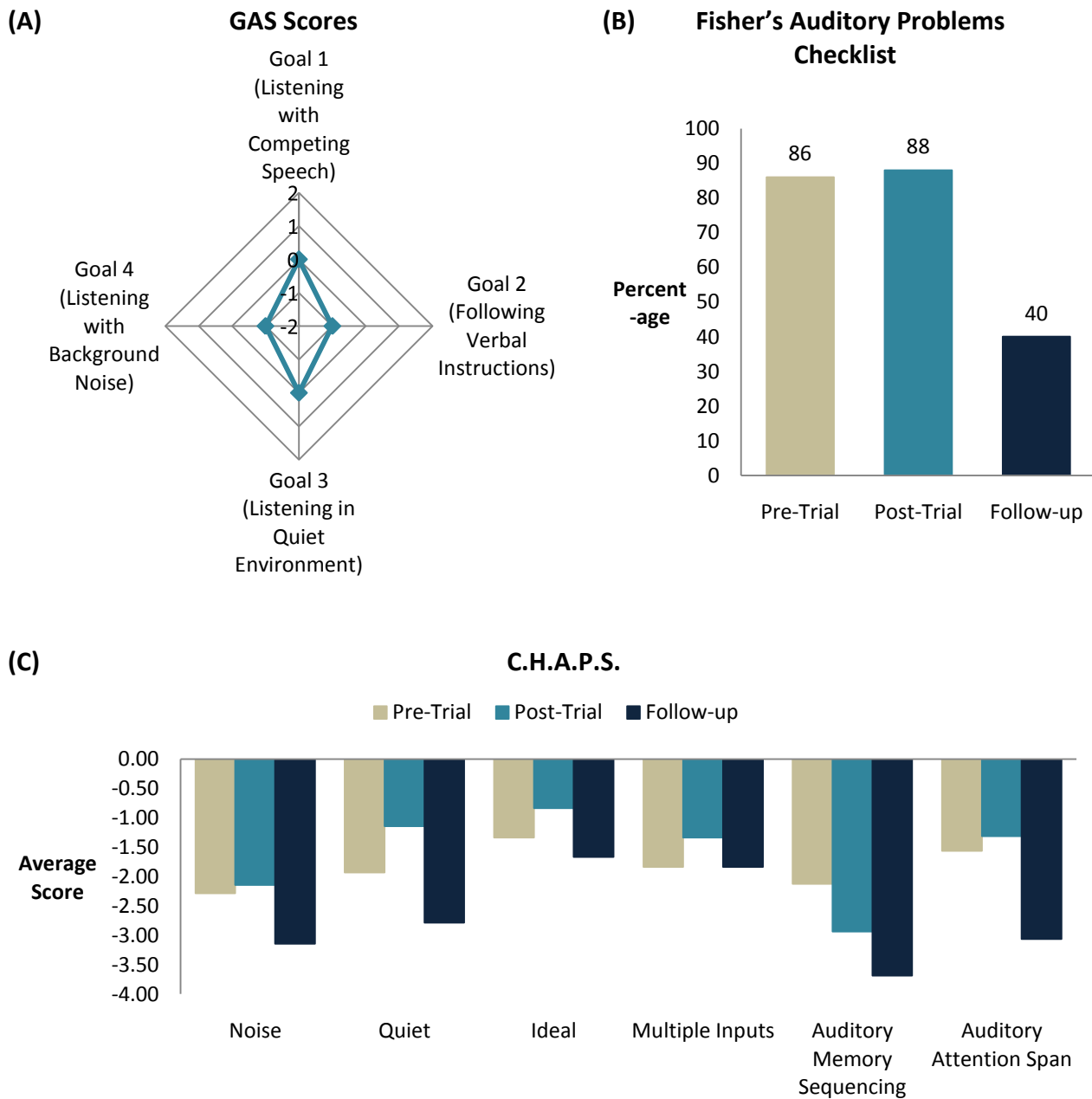


Figure 28. Changes in Participant 22's (A) GAS scores pre- and post-stimulation period; (B) total percentage score from the Fisher's Auditory Problems Checklist across the three sampling points; and (C) average scores on the six conditions from the C.H.A.P.S. across the three sampling points.

3.6.4. Case 4 - Participant 3

Participant 3 was a male aged 11 years 1 month who presented with dyspraxia. He was frequently found to be disengaged during group activities, easily distracted and often had difficulty following instructions in noisy situations despite having normal peripheral hearing. His mother reported that he had difficulty detecting humour or sarcasm in remarks, understanding people who speak quickly and understanding nonverbal cues. His voice was often monotonic and he was sensitive to loud sounds. It was noted that there was a family history of middle ear infections: all three of his brothers and he himself had bilateral ventilation tubes inserted in childhood. His mother further reported that he had had more than ten ear infections since birth. His mother reported that a cranial ultrasound revealed a mild enlargement of the lateral ventricles. She further reported that his developmental milestones were delayed: he starting crawling at 14 months and walking at 18 months. Prior to attending his current school, he was struggling in the mainstream setting as his speech and language was severely delayed. His speech was often unintelligible and consisted of many age-inappropriate phonological processes such as gliding (/r/ → /w/). He was also having significant difficulty with reading, spelling and writing (e.g. reversing letters and numbers).

Figure 29 and Figure 30 represent his performance on objective and qualitative measures respectively. His spatial stream segregation skills, phonological memory and reading rate were greatly enhanced following eight weeks of FM use. His syllable segregation skills, targeted specifically in class during the study, also improved. While his teacher also noted an improvement in his auditory processing skills, as demonstrated by an improvement in the percentage on the Fisher's Auditory Problems Checklist and the GAS scores, his C.H.A.P.S. scores were progressively worse throughout the course of the study. Anecdotally, the teachers noted, for the first time, that he was actively listening and participating during story time, instead of "daydreaming" as he did prior to the FM trial. Despite the benefits he appeared to be getting from using the FM system, he was the only participant who reported that the FM devices were "terrifying" and he did not like wearing them at all.

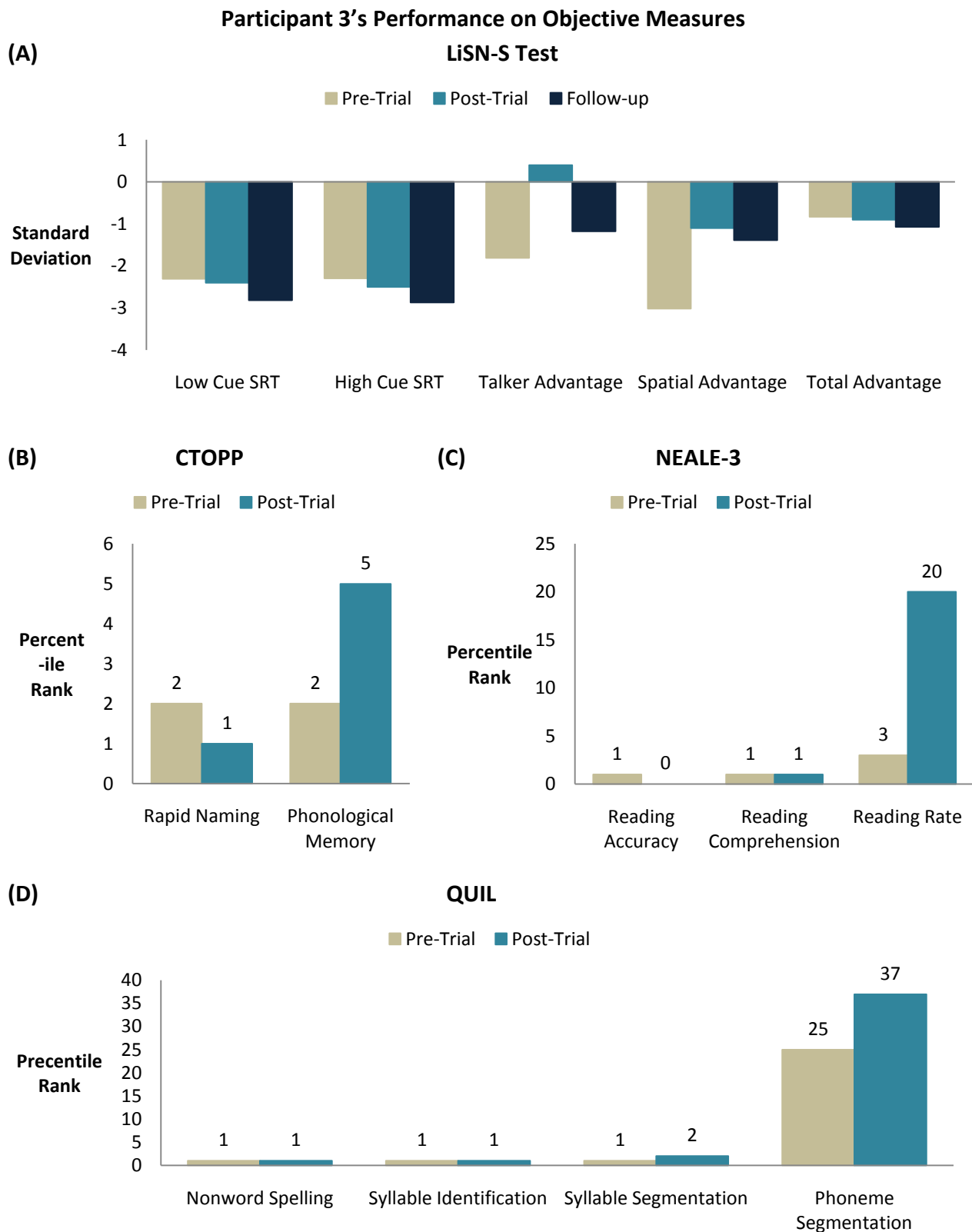


Figure 29. Participant 3's performance on the (A) LiSN-S test before, immediately after, and eight weeks following stimulation; and his performance on the (B) CTOPP, (C) NEALE-3 and (D) the QUIL before and after stimulation.

**Participant 3's Performance on the GAS, Fisher's Auditory Problems Checklist
and C.H.A.P.S. Scores**

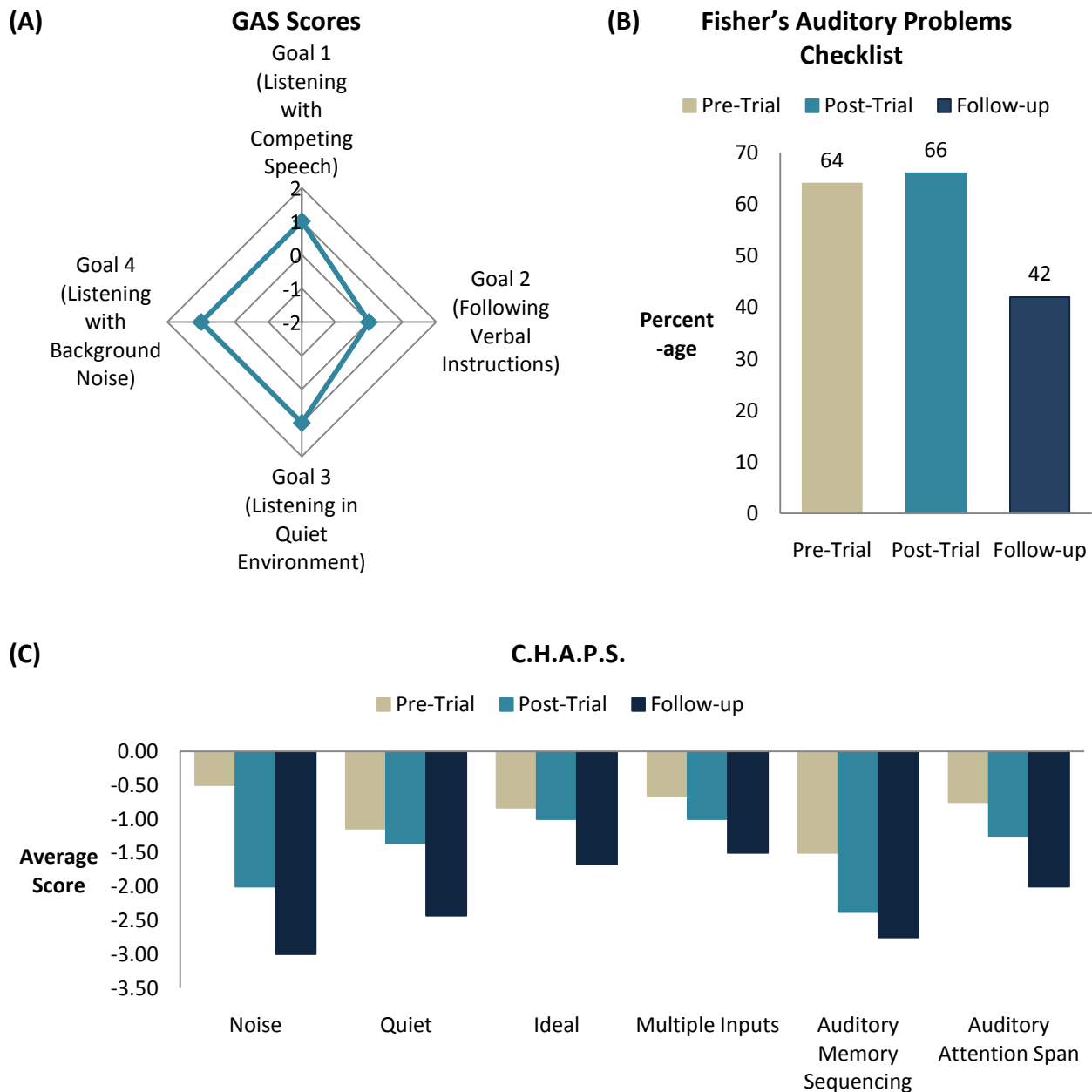


Figure 30. Changes in Participant 3's (A) GAS scores pre- and post-stimulation period; (B) total percentage score from the Fisher's Auditory Problems Checklist across the three sampling points; and (C) average scores on the six conditions from the C.H.A.P.S. across the three sampling points.

CHAPTER 4. DISCUSSION

4.1. *Personal FM Systems as an Intervention for Spatial Stream Segregation Deficits*

The International Classification of Functioning, Disability and Health (ICF) is a universal conceptual framework for the description of health and disability (see Figure 31 below). Briefly, the ICF framework looks at how changes in body function and structures due to a health condition can impact on an individual's ability to function (i.e. "body functions and structures", "activities", and "participation") in a standard environment (i.e. capacity level), and in their daily environment (i.e. performance level). As a particular intervention for a diagnosis does not necessarily predict functional outcomes, the ICF is particularly useful as an intervention planning or evaluation tool as it emphasizes the relationship between health, functioning and quality of life. However, the ICF has not been commonly utilised in intervention studies of APD. The present study attempted to capture the impact of personal FM systems as an intervention on children with a spatial stream segregation disorder at the levels of body functions and structures, activity and participation based on the ICF framework.

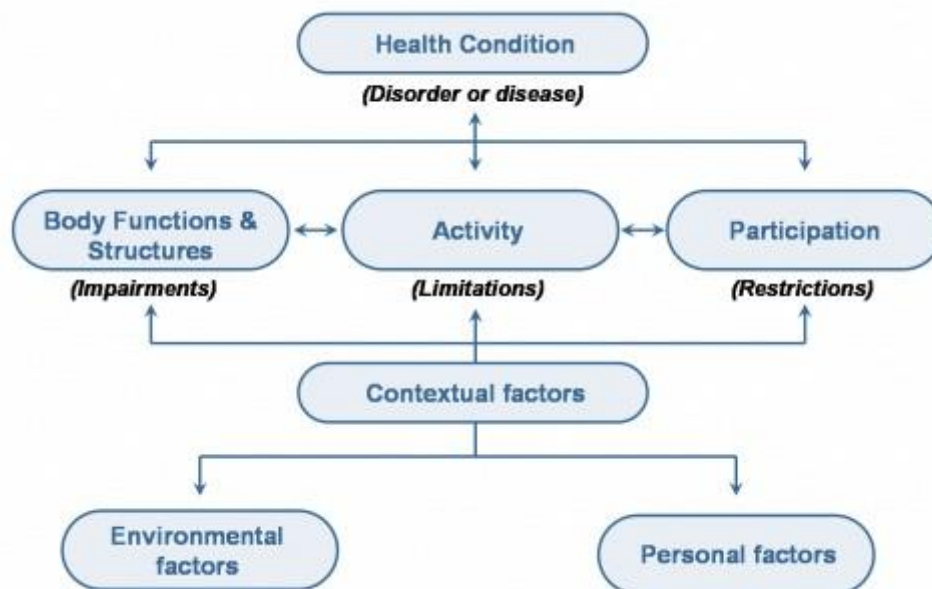


Figure 31. Representation of the model of disability based on the International Classification of Functioning, Disability and Health (ICF) model.

While the underlying neurological condition of a child with APD is largely unknown, the pathology has been demonstrated to manifest as an impairment of spatial processing in at least

a subset of children with APD (Cameron & Dillon, 2008; Cameron, Dillon, & Newall, 2006). This impairment consequently results in a communication difficulty and the child's ability to hear in the classroom is adversely affected (i.e. limitations). This in turn may restrict the child's ability to engage in story time, follow instructions, and listen to the teacher in the presence of background noise and/or competing speech (i.e. restrictions). By providing an FM system as an intervention, we have demonstrated, in at least 7 of the 10 participants, improvements at the body function level as reflected in an improved score on the LiSN-S measures (i.e. improvement in their ability to hear in background noise); and improvements in the participation restrictions level following the 8-week FM trial (i.e. improved scores on the GAS goals and the Fisher's Auditory Processing Checklist).

4.1.1. Effects of FM Stimulation on Spatial Stream Segregation

Spatial stream segregation deficit has been reported in children with APD (Cameron & Dillon, 2008) and without (Cameron, et al., 2006) other comorbidities including language, learning and attention deficits (Cameron & Dillon, 2008; Cameron, et al., 2006). Cameron and colleagues reported that nine out of ten children with APD from their study in 2006 and five out of nine children with APD from their study in 2008 performed on average 5 and 2 standard deviations (SD) outside the normal limits respectively when the target speech was spatially different from the competing speech. However, all children from the APD group in both studies performed within normal limits when the target speech and the competing speech were not spatially different. These results suggested that children with APD, whose primary difficulty was listening to speech in noisy environments, such as in the classroom, may have an impaired ability to integrate information binaurally and make use of spatial information to direct their attention to the target speech away from the noise in the background. In light of these findings, Cameron and colleagues (Cameron & Dillon, 2008; Cameron, et al., 2006) suggested the need to improve SNR in the classroom, via either a personal or sound-field FM system (Cameron & Dillon, 2008) as one of many possible intervention strategies to facilitate the establishment of spatial streams.

Indeed, technology designed to maximize the SNR, such as FM systems, is often suggested as an intervention strategy for children with APD (ASHA, 1991; ASHA, 2005d; Beck & Bellis, 2007; Bellis, 2003; Bellis & Anzalone, 2008; Cameron & Dillon, 2007b; Cameron, et al.,

2006; Smaldino & Crandell, 2000; Weihing, 2005; Whitelaw, 2003) and the benefits and effectiveness of FM has been documented (Johnston, et al., 2009; Smart, et al., 2010; Stach, Loisel, Jerger, Mintz, & Taylor, 1987). However, as highlighted by many (e.g. Moore, Halliday, & Amitay, 2009; Rosenberg et al., 1999; Stach, et al., 1987; Whitelaw, 2003), including a recent systematic review by Lemos and colleagues (2009), the recommendation of FM systems for this population is largely based on experts' opinions and evidence-based research on the effectiveness of FM systems as an intervention for the more general APD population, as well as for those who demonstrate a spatial stream segregation deficit, is scarce.

In the present study, we hypothesized that children with a spatial stream segregation deficit would benefit from 8-weeks of use of a personal FM system, and that this benefit would be maintained following withdrawal of the FM system for a period of eight weeks. This hypothesis was partially supported by the data. Five out of eight children identified as having a spatial stream segregation deficit in this study demonstrated an improvement on their spatial processing (from outside to within 2 SD) following eight weeks of FM stimulation. Additionally, this improvement was maintained for at least eight weeks following the withdrawal of FM stimulation. Based on studies in the visual modality, it has been proposed that auditory information can be discriminated into different "streams", which guides the listener's "selective attention" (Best, Ozmeral, Kopčo, & Shinn-Cunningham, 2008). However, a listener's selective attention to an acoustic stimulus (or an auditory object) changes depending on many factors, including the inherent salience of the stimulus (Conway, Cowan, & Bunting, 2001), the complexity of the acoustic properties of the stimulus (Shinn-Cunningham, 2008b), and the listener's top-down attention (Best, et al., 2008; Kidd, Arbogast, Mason, & Gallum, 2005). The bottom-up salience of an acoustic stimulus is important for "object formation" (i.e. the perception of an auditory stimulus as coming from a single discrete source in the environment), where better formation of a stream can be achieved by increasing the SNR or when it is of particular relevance – such as your name (Conway, et al., 2001). The formation of an auditory object, however, is enhanced over time, usually within seconds (Shinn-Cunningham, 2008a). On the other hand, the complexity of an acoustic stimulus is important for "object attention", where more complex speech-like signals are better at attracting and maintaining the listener's auditory spatial attention over time (Best, et al., 2008). Thus, degradation in the bottom-up salience of an acoustic stimulus is likely to result in poor and slow object formation; while poor

object attention result in poor and slow selective attention or spatial stream formation, which may manifest as poor listening skills when background noise or competing speech is present.

Prior to this study, the children from the FM group had difficulty forming auditory objects and forming appropriate streams due to difficulty processing spatial cues. This made listening to their teacher's speech particularly challenging when other background noise and /or competing speech were present. The personal FM systems used in this study facilitated the children's ability to attend to a target auditory signal (i.e. their teacher's voice) in the presence of competing noise by increasing the SNR. This assisted the children to focus their attention on their teacher's speech, which was made more salient. The fact that the children were able to maintain their improved spatial processing performance following withdrawal of the devices may indicate improved top-down attention skills that better their ability to suppress other competing acoustic sources.

Furthermore, neuroplasticity and neuromaturation of the auditory pathways are enhanced following increased stimulation of the auditory cortex (Kitzes, Farley, & Starr, 1978; Kraus, et al., 1995). Evidence suggests that it is possible the direct auditory stimulation provided by a personal FM system may enhance neural plasticity and facilitate auditory neuromaturation (Friederichs & Friederichs, 2005). Friederichs and Friederichs (2005) reported significant improvements in the auditory late event-related potentials (AERPs) in ten children with APD following the use of personal FM systems for six months; these changes were not observed in control participants. Although cortical potentials were not measured in this study, it is possible that the improvement in spatial stream segregation skills found in the participants from the FM group was related to enhanced neuroplasticity and neuromaturation of the auditory pathways.

While it is unlikely that the improvements were due to a practice effect, evidence suggests that memorization of materials or training effects are possible, especially when they that are not designed to be administered repeatedly over short periods (e.g. McArthur, Ellis, Atkinson, & Coltheart, 2008). Given that the control group demonstrated no significant changes on their spatial stream segregation ability throughout the study, a practice effect is unlikely.

4.1.2. *Effects of FM Stimulation on Memory Deficits*

Two children (Participants 2 and 9) from the FM group were included due to their poor performance on the LC and HC SRTs from the LiSN-S test. This pattern has been suggested to be associated with memory deficits (Cameron, 2011). Cameron and Dillon (2010) reported a case of an 8 year 3 months old male who had difficulty listening in background noise and scored poorly on the Recalling Sentences task from the Clinical Evaluation of Language Fundamentals – Fourth Edition (CELF-4). On the LiSN-S, his performance on the LC SRT and HC SRT was much poorer than compared to that of the advantage measures. It was proposed that his auditory processing abilities were compromised because the child had to allocate greater cognitive resources to remembering the target sentences. The findings from the present study demonstrated an improvement in Participant 2 and 9's performance on the both the LC and HC SRT following eight weeks of FM stimulation. This improvement was maintained even after the withdrawal of the FM systems.

Although it is difficult to determine the cause(s) of the apparent improvement in Participant 2 and 9's memory capacity, if indeed that is what their LiSN-S test results reflect, it is possible that, increasing the SNR via an FM system facilitates the development of improved object formation and selection. This may result in a lightening of the cognitive load required for attending to a target signal, leaving more resources available to allocate to retention and retrieval that target. Animal models have demonstrated that top-down factors, including attention (Benson & Hienz, 1978), and working memory (Pasternak & Greenlee, 2005), can affect auditory cortical activity. In addition, neuroanatomical evidence in both human and animal studies have demonstrated that auditory cortical neurons are actively involved during working memory tasks involving the retention and retrieval of auditory information (Ojemann, Schoenfield-McNeill, & Corina, 2002; Sakurai, 1994). Wang (1997) reported significant improvement in the short-term memory of three primary school children with ADHD following eight weeks of FM stimulation via sound field. Clearly, the interplay between sensory and cognitive processes in tasks such as listening to a target signal embedded in background noise requires further investigation, particularly with reference to clinical interventions for such difficulties in children with APD.

It should be noted that given the design of this study, a practice effect cannot be ruled out in these two individuals. However, given that none of the control children showed significant improvements over the three time points assessed, this seems unlikely.

4.2. *The Effect of Personal FM Systems on Reading*

Contrary to our hypothesis, the findings from the current study indicate that the use of an FM system did not significantly enhance the reading and comprehension of connected text in the FM group participants. However, the children from the FM group demonstrated, albeit statistically insignificant, increased accuracy in reading and comprehension of connected text, as well as significantly faster reading rate after eight weeks of FM stimulation. Similar findings on the benefits of the use of personal FM systems on reading and comprehension have been demonstrated for children with reading difficulties (Purdy, Smart, Baily, & Sharma, 2009). Following six weeks of FM stimulation, Purdy and colleagues (2009) reported a significant improvement in the experimental children's reading age. However, such improvement was not significantly different to the control children's improvement. The authors concluded that the short stimulation period coupled with a lack of specific reading intervention and non-comprehensive reading assessments contributed to the lack of significant improvements. While the reading assessments used in the present study were very comprehensive, our stimulation period was also relatively short (i.e. eight weeks). Evidence from studies that involved trial-periods of five months to three years has readily demonstrated the benefits of classroom amplification on normal developing children's reading comprehension (Darai, 2000; Flexer, 2000; Rosenberg, et al., 1999) and phonological awareness (Flexer, Biley, Hinkley, Harkema, & Holcomb, 2002; Good, 2009; Sarff, et al., 1981). Darai (2000) reported significantly greater literacy development for children without APD, who were placed in classrooms with sound field amplification (n=85) compared to those who were without amplification (n=81) for 5 months. Likewise, Rosenberg and colleagues (Rosenberg, et al., 1999) reported improvements in children's reading and learning in general, when placed in amplified classrooms. Flexer (2000) reported after seven months of used of sound-field amplification, 74% of normal developing children in first-grade (n=54) performed at or above "basic" level on the Utah State Core Reading Test, as opposed to approximately 48% prior to the study.

Furthermore, in the present study, the opposite trend was observed in the control group, where their performance seemed to decline (insignificantly), on at least two out of three measures (i.e. the accuracy of reading and comprehension) eight weeks into the study. Given that all children in the present study exhibited severe reading impairment (i.e. below 10th percentile for reading accuracy and reading comprehension scores) and no specific reading interventions were introduced in parallel with the introduction of the personal FM systems, it is encouraging to see that the FM group improved while at the same time the control group declined on measures of literacy. This further highlights the potential benefits of personal FM systems for children with APD and reading impairment. The lack of significance in the results, therefore, may merely reflect the small statistical power (see Table 7 from Section 3.2.2) due to small sample size.

4.3. *The Effect of Personal FM Systems on Phonological Awareness*

We hypothesised that the use of FM systems would result in an improvement in the children's phonological awareness and processing skills. Our findings indicated that eight weeks of FM stimulation resulted in improvements, albeit insignificant, to all participants' phonological awareness and phonological processing skills. A significant improvement was noted in the syllable segmentation task from the QUIL. This was a skill that happened to be specifically targeted within the classroom during the study period; however it should be noted that while the FM participants significantly improved on their ability to segment syllables over the study period, a significant improvement was not seen in the control children, despite receiving the same classroom teaching. Previous studies utilizing FM systems in conjunction with focused teaching have reported improvement in phonological awareness (Flexer, 2002; Flexer, et al., 2002; Good, 2009; Sarff, et al., 1981). Flexer and colleagues (2002) found that the smallest number of at-risk readers were found in classrooms equipped with sound field systems.

As with the findings for reading, the minimal improvement across the phonological awareness measures used in this study may be related to the lack of a specific PA intervention implemented during the course of the study. Good (2009) demonstrated implementation of sound-field amplification combined with classroom-based phonological awareness training, compared to just sound-field amplification alone, resulted in a significant improvement in the

children's phonological awareness skills. However, this improvement was minimized when beginning (i.e. syllabic level such as rhyme awareness) as opposed to advanced (i.e. phonemic level such as phonemic segmentation) skills were targeted in the intervention. While phonological awareness is an integral part of the school curriculum, the teachers from the present study focused on lower-level phonological awareness skills, which was appropriate for these children. It is important to note, however, that all participants in this study had severe comorbid learning difficulties. They were severely delayed in their literacy and phonological awareness development compared to typically developing children and had been struggling with the acquisition of these skills in the mainstream school system prior to attending the private school in which this study was based. For this reason, it is not surprising to see limited improvements with regards to their phonological awareness, reading, comprehension and spelling skills over the relatively short duration of this study.

4.4. The Effectiveness of FM from a Teacher's Perspective

Prior to the study, we hypothesised that the teachers would see a post-trial improvement in the FM children's auditory behaviours, and we further hypothesized that they would continue to see these enhanced behaviours following the withdrawal of the use of the FM systems for eight weeks. The findings from this study suggest these hypotheses were partially met. Specifically, the questionnaires completed by the teachers in this study revealed two interesting findings. Firstly, there was a significant inter-rater difference within Room 1 and Room 2 on the C.H.A.P.S. and the Fisher's Auditory Problems Checklist, which was consistent across the three sampling points. Previous studies have reported similar inter-rater differences between parents and teachers (Kuk, et al., 2008). Since only one of the teachers involved in this study had some basic knowledge of FM systems, the apparent inter-rater differences may simply reflect differences in the inherent expectations of FM by different teachers. A more likely explanation is that the teachers may have had differing expectations of the children's capabilities in comparison to their peers. The teachers from Room 2 commented before the FM trial that they found it particularly difficult to complete the questionnaires as they had 'never really specifically thought about the children's auditory behaviours before'.

In addition to these inter-rater differences, changing expectations of the children across the study period may have also resulted in intra-rater variation. That is, perhaps observing the

positive impact the FM systems had on the children's auditory behaviours during the trial raised the teachers' expectations of the children, thereby causing them to rate them more harshly after the trial than before. This is particularly relevant to the interpretation of the results of the C.H.A.P.S questionnaire which indicated a *decline* (albeit insignificant) in FM participants' post-trial auditory behaviours. Anecdotally, the teachers reported that they observed an improvement in the FM participants' post-trial auditory behaviours, which is in marked contrast to their ratings on the C.H.A.P.S questionnaire.

These significant inter- and intra-rater differences highlight the difficulties inherent in using questionnaires that involve comparing children to other children. The GAS scores, on the other hand, more closely aligned with the teachers' anecdotal reports of positive improvements in auditory skills and behaviours with FM use. The GAS asks raters to compare a child to himself after a given time period, using his current skills and behaviours as a baseline for judging improvements. Rather than a set of arbitrary expectations, specific goals are written based on the likely and most optimistic expectations for that child. The rater is therefore reflecting on improvements observed in that individual over a set time period, rather than trying to compare the child to a fictitious ideal.

Secondly, the teachers' perception of the impact of the use of personal FM systems on the FM students' auditory behaviours appeared to differ depending on which of the three qualitative measures was used. The teacher's ratings on the GAS suggest that they perceived an improvement in the FM children's auditory behaviours across various settings. However, their post-trial ratings on the Fisher's Auditory Problems Checklist revealed a small but insignificant improvement, while the C.H.A.P.S. scores reported an insignificant decline over time. A number of factors may contribute to these findings.

The C.H.A.P.S. scores reported in this study for the children from the FM group seem to mismatch their improved performance on the LiSN-S test. Cameron and colleagues (2005) also reported in a case study an inconsistency between the child's poor performance on APD assessments and the C.H.A.P.S. score reported by her teacher. This child had had a significant history of OME and was fitted with ventilation tube. Her spatial advantage score and her performance on the random gap detection test was 5 and 6 SD below mean respectively. Her mother and special education teachers all reported that she was experiencing significant

difficulty understanding speech in noisy environments. However, her teacher gave her an overall C.H.A.P.S. score of -0.1 , a score which indicated that her teacher perceived her as having about the same amount of difficulty as her peers. Further investigation revealed that the highly structured activities provided by the child's teacher masked the true level of difficulty the child was having. The C.H.A.P.S questionnaire was reportedly a challenge for the teachers in this study, as they were required to compare the FM participants to mainstream school children of the same age. These teachers themselves hadn't worked with children from mainstream schools for many years, and their expectations of auditory behaviours were based on their daily interactions with children who typically struggle with auditory processing skills.

While the C.H.A.P.S. is useful in highlighting concerns regarding a child's listening difficulties (Sharma, et al., 2009; W. J. Wilson et al., 2011), it was not an appropriate evaluation tool in our case due to the unique dynamic of the current school. Other evidence suggests that diagnostic/screening with C.H.A.P.S. should also be cautioned (Sharma, et al., 2009; W. J. Wilson, et al., 2011).

The teachers reported improved GAS attainment scores for the FM group across all four goals, with only two children gaining a T-score of less than 50, indicating the goals were set at an appropriate level (neither over-cautiously nor over-ambitiously; Turner-Stokes, 2009). The GAS is an excellent tool to evaluate an individual's progress towards predetermined goals and can be adapted to any ICF levels. It is widely used in other clinical professions including occupational therapy (e.g. Graham & Rodger, 2010; Graham, Rodger, & Ziviani, 2010), mental health (e.g. Izycky, Braham, Williams, & Hogue, 2010), nursing (e.g. Becker, Stuifbergen, Rogers, & Timmerman, 2000), geriatric care (e.g. Davis & White, 2008), rehabilitation (e.g. Rockwood, Joyce, & Stolee, 1997; Turner-Stokes, 2009), early intervention (e.g. O'Connor & Stagnitti) and physical therapy (e.g. Klepper, 2007; Palisano, Haley, & Brown, 1992). However, it is not yet recognised within audiology. One challenge that many face with the GAS, as the teachers in this study found, is the specification of the criteria necessary for a continuum of possible outcomes (Schlosser, 2004). Providing that these outcomes are established accurately and envisioned realistically, the reliability of GAS is high.

The inconsistency between the teacher's ratings on the C.H.A.P.S., the Fisher's Auditory Problems Checklist and the GAS seems to reflect the unreliability of some of these qualitative

measures. However, careful analysis reveals that the “scales” utilised in each of these measures are very different. While the C.H.A.P.S. requires the teachers to compare a child’s performance against his/her normal developing peers, the Fisher’s Auditory Problems Checklist requires the teachers to check relevant items to characterize the child of concern. The GAS, however, is an individualized 5-point scale developed by the teachers with the child’s current ability taken into considerations. In addition, a child may demonstrate small but real functional improvements in their auditory behaviours, but may still exhibit those characteristics listed in the Fisher’s Auditory Problems Checklist and continue having more difficulties with auditory processing than his/her peers as shown in C.H.A.P.S.. Therefore, the GAS is likely to capture smaller, functional but realistic improvements within an individual and accounts for partially attained or exceeded goals with better sensitivity than the more generic measures such as the C.H.A.P.S. and the Fisher’s Auditory Problems Checklist. Thus, as hypothesized, the benefits of FM use were perceivable to the teachers in this study as reflected by the GAS.

4.5. *Clinical Implications*

Because of APD’s heterogeneous nature, diagnosis and management remain somewhat difficult. Evidence suggests that a subset of children with APD who experience difficulty with speech perception in noise may be related to a spatial processing impairment (Cameron & Dillon, 2008; Cameron, et al., 2006). These children’s abilities to follow instructions, listen to their teachers in class and engage during story time are adversely affected. The present study demonstrates the LiSN-S test is useful in identifying these children and verifying the benefits of the use of FM system on speech perception in noise. Our study supports the emerging evidence that personal FM system may be an effective tool for breaking the barriers to learning (Johnston, et al., 2009; Smart, et al., 2010).

However, successful implementation of FM systems in the classroom depends on the teacher and child’s attitude and compliance. Many steps can be taken to make this process a more positive one. Firstly, the audiologist should educate the students, teachers and parents/caregiver on basic principles of hearing, APD and FM systems. Secondly, the teacher should be provided with opportunities to gain confidence with the operation of the FM system. In the present study, the teachers were given the FM system to trial one week prior to the trial, with supervision. Additionally, all children, including those from the control group, were

encouraged to trial the FM receivers. This was particularly important as it satisfied the children's curiosity, but more importantly, it helped minimize the stigma of personal amplifications by allowing the children to experience how amplification may help other children and their learning. Audiologists may also wish to put the responsibility for caring of the devices on the child, as this can reduce the teacher's stress, as noted in this study, and making the FM trial more positive.

As the evaluation process is important in determining the effectiveness of the FM system, the audiologist's choice of measuring tools is critical. Our findings support the use of C.H.A.P.S. and the Fisher's Auditory Problems Checklist as means to draw the teacher's attention to the auditory difficulties experienced by the child of concerns. However, the GAS has potential to be a better tool for determining the benefits of the FM systems and document the child's progress within and across different auditory learning goals. As the data from the current study demonstrate, the GAS was able to capture small, functional improvements that other generic qualitative measures may overlook.

4.6. Limitations

While this study is unique in that participants from each classroom were exposed to the same acoustic environment and teachers, several limitations may have contributed to the findings. Due to the relatively small sample size, caution must be taken with the interpretation and generalisation of the results from this study to the wider population. Additionally, an A-B-A experimental design, where the participants were not required to demonstrate a stable baseline prior to the beginning of the FM trial, was employed. Studies of auditory learning in children with APD have demonstrated that a learning/training effect owing to the repeated exposure to assessment materials is possible, especially during the early phase of the study (Amitay et al, 2006; Tallal et al, 1996). The establishment of a stable baseline would have enhanced the validity of the present findings. Additionally, because the control participants from our study demonstrated normal spatial stream segregation ability, caution must be taken with the interpretation of the present findings.

The current study also faces the inherent difficulty in experiments where personal FM systems are involved, that is, the fact that the teachers are not blinded to which student from

their class received amplification. Inherent teacher bias was unavoidable. Furthermore, all children in this study had significant comorbidities (e.g. SLD, literacy impairments, dyspraxia and dyslexia) and the improvements demonstrated on all measures may have been smaller than what would be expected in the wider population. A short trial period may have also limited the generalisation of the children's auditory skills to other areas, such as PA and literacy.

Finally, despite regular visits to the school by the author, and making every attempt to ensure the equipment was set up and running smoothly, occasionally, during the beginning of the trial, the lapel microphone was worn the wrong way up (resulting in a static noise as the microphone rubbed against the teacher's clothes) for a short time, or was not worn close enough to the teacher's mouth (resulting in a reduced SNR). On rare occasions, FM systems were found with wax guards or batteries needing replacing. These issues, however, were generally rare, due to the high level of contact maintained with the participants by the author, and were further minimised, in one of the classrooms where a student, who was very enthusiastic about the FM systems, was given the responsibility for device maintenance. Nonetheless, regular contact with the teacher of a child with an FM system is imperative, especially towards the beginning of the FM trial, to ensure technical issues are minimized.

4.7. *Future Directions*

While the present study demonstrated some promising findings, future studies should consider the following suggestions to further ascertain the effectiveness of personal FM systems for children with spatial processing deficits, as well as APD in general. It has been previously demonstrated that enhancement of neuroplasticity and acceleration of neuromaturation following sensory stimulation (or behavioural training) is possible (e.g. Friederichs & Friederichs, 2005) and can precede behavioural changes (Kraus, et al., 1995; Tremblay & Kraus, 2002). Further studies on children with APD and spatial stream segregation deficit that incorporate auditory evoked potential (AEP) measures with behavioural measures may shed light on specific neurophysiological changes in the auditory pathways (and other sensory pathways) that occur following FM stimulation. Further behavioural studies complemented with AEP measures may also better our understanding regarding the impact of personal FM system use on neural synchrony.

Larger studies with longer trial periods in parallel with specific auditory, reading or PA intervention conducted in mainstream settings is also recommended, and may also assist in the determination of the optimal trial length to maximise the benefits of personal FM systems for children with APD. Training or practice effect should be minimized by incorporating multiple (or stable) baseline assessments. Lastly, GAS should be considered as a qualitative measure for evaluating the functional success of an FM trial.

4.8. *Conclusion*

The management of APD is a fascinating area of research and good-quality scientific evidence on the effectiveness of FM systems in this heterogeneous group is just beginning to emerge. The current study indicates that the use of personal FM systems may be beneficial for children with APD secondary to spatial stream segregation deficits, who are struggling to listen to speech in noisy environments despite having normal peripheral hearing. While it is tempting to focus on fixing the “impairment” - such as spatial stream segregation deficit in this case - audiologists must not neglect the functional impact of the impairment on the child in a wider context. Although limited benefits were evident in the children’s literacy and PA development, the reader is reminded that the children from the current study all had severe SLD and had been struggling academically and socially in mainstream settings. Moreover, audiologists should be cautious when choosing qualitative evaluation tools. Goal Attainment Scaling (GAS) is a good option for capturing functional progress that is specific to the child.

Existing evidence on the provision of more focused speech and language intervention in parallel with the use of personal FM systems have shown promise. FM systems are clearly a part of the management process and do not substitute other means of intervention (e.g. auditory training, speech and language therapy, reading interventions): a multidisciplinary approach, from implementation to evaluation of the FM system, is essential for the optimisation of the outcome.

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APPENDIX 1 - HUMAN ETHICS COMMITTEE APPROVAL LETTER

Ref: HEC 2010/17

25 March 2010

Fiona Yip
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Fiona

The Human Ethics Committee advises that your research proposal “Personal FM systems in children with Auditory Processing Disorder as determined by the LiSN-S test” has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 16 March 2010.

Best wishes for your project.

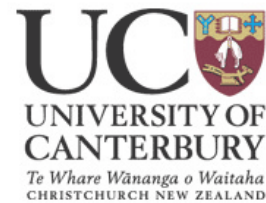
Yours sincerely

Dr Michael Grimshaw
Chair, Human Ethics Committee

APPENDIX 2 – PARENT INVITATION FOR PARTICIPATION

University of Canterbury

Department of Communication Disorders



Invitation

TO PARTICIPATE IN RESEARCH

Personal FM Systems in Children with Auditory Processing Disorder as Determined by the LiSN-S Test

Dear Parents,

We would like to invite your child to participate in a research project carried out as a requirement for a Masters of Audiology titled *Personal FM Systems in Children with Auditory Processing Disorder as Determined by the LiSN-S Test*.

The aim of this project is to determine the effectiveness of ear level FM devices as an intervention for students with auditory processing disorder (APD), specifically those who have difficulties with spatial segregation (i.e. ability to separate sounds coming from different directions). We ask you to please take your time to read the two **Project Information Sheets** enclosed (one for you and one for your child), which provide the details of this project.

As part of this project, your child will be provided with a free hearing assessment. For this purpose, enclosed in this "Parent Information Pack" are two **consent** forms (one for you and one for your child) and a **parent questionnaire**. The consent forms authorize both your child's participation in this project and the information your child provides to be used for research purposes only. The parent questionnaire provides us with the information regarding your child's birth, developmental, medical, audiological and academic history. We would appreciate it if you would **complete and return* the consent forms by Friday 19th March 2010** and the **parent questionnaire by Monday 22nd March 2010**. (*Please return the completed form to your child's class teacher.)

Please feel free to contact me with any questions or comments you may have about participation in the project. The project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

Kind regards,

Fiona Yip
Masters of Audiology Student
Department of Communications Disorders
University of Canterbury
Private Bag 4800
Christchurch, New Zealand
Email: fiona.p.yip@gmail.com

Mobile: +64 21 2666 337

APPENDIX 3 – PARENT INFORMATION SHEET

University of Canterbury

Department of Communication Disorders



PROJECT INFORMATION SHEET

FOR THE RESEARCH STUDY

Personal FM Systems in Children with Auditory Processing Disorder as
Determined by the LiSN-S Test

PARENT INFORMATION

Your child is invited to participate in the research project *Personal FM Systems in Children with Auditory Processing Disorder as Determined by the LiSN-S Test*.

AIM OF PROJECT

The aim of this project is to determine the effectiveness of ear level FM devices as an intervention for students with auditory processing disorder (APD), specifically those who have difficulties with spatial segregation (i.e. ability to separate sounds coming from different directions).

PROCEDURES

Your child's participation in this project involves a number of tasks, which are outlined as follows:

A. Pre-fitting assessment*Time required: 1 ½ - 2 hours*

- Case History

Time required: 5-10 minutes

Information regarding your child's birth, developmental, medical, audiological and academic history will be obtained. The parents and teachers will be the primary source for this information.

- Hearing Screening

Time required: 10 - 20 minutes

Your child's hearing will be assessed in a quiet room at the school. Specifically, an *otoscopy* will be performed to visually examine the health of your child's ear canals and ear drums.

Pure tone audiometry will be performed to assess your child's hearing sensitivity.

Specifically, his/her hearing will be screened down to 15 dB HL across the important speech frequencies. Various tones will be presented via insert earphones or supraaural head phones. He/she will be asked to press a button each time they hear the tone to indicate they have heard the sound.

- APD Testing *Time required: 45 minutes*
Your child's ability to understand speech in the presence of competing speech using the Listen in Noise – Sentences (LiSN-S) Test. Your child will be asked to repeat a target sentence in the presence of noise presented via a pair of specialized circumaural headphones. A speech reception threshold (SRT) will be obtained under each of the four conditions.
- Neale Analysis of Reading Ability Test *Time required: 20 - 45 minutes*
Your child will be instructed to read aloud a number of short stories of increasing length and difficulty. They will be timed and a score will be calculated according to the accuracy of their reading.

B. Trial of the FM system

Time required: 8 weeks

Your child will be fitted with a pair of personal FM devices for a period of 8 weeks (in line with current Ministry of Education trial for government funded FMs), while the teacher wears the transmitter all day in one classroom. During this trial period, your child will be encouraged to wear the FM devices provided throughout the entire school day. All FM devices are strictly for use at school during the trial period.

C. Reassessment

Time required: 1 - 1 ½ hours

At the end of the 8-week trial and again following another 8-week period, your child will be reassessed using the Neale analysis of reading ability test as described in details above.

ELIGIBILITY FOR THE PROJECT

In order for your child to participate in this project, they must meet ALL of the following criteria:

- He/she must be between the age of 7 to 11 years;
- He/she must speak English as their first language;
- He/she must have hearing better than a Pure Tone Average (PTA) of 20 dB at 500, 1000, 2000 and 4000 Hz.
- His/her spatial advantage score on the LiSN-S test is outside normal limits of their age group (i.e. they show evidence of spatial streaming segregation difficulties).

WITHDRAWAL & CONFIDENTIALITY

Your child has the right to withdraw from the project at any time, including withdrawal of any information provided.

The results of the project may be published, but your child is assured of the complete confidentiality of data gathered in this investigation. The identity of your child will not be made public without their consent.

In order to ensure anonymity and confidentiality, the information gathered will be assigned a code number and all identifiable information removed. Data will be kept in a locked filing cabinet within a lockable room in the Department of Communication Disorders.

The project is being carried out as a requirement for a Masters of Audiology by Fiona Yip, under the supervision of Dr. Natalie Rickard, who can be contacted at the University of Canterbury on +64 3 364 2987 ext. 3052. We will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed **and approved** by the University of Canterbury Human Ethics Committee.

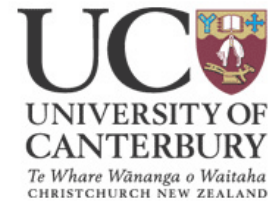
Fiona Yip

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APPENDIX 4 – TEACHER INFORMATION SHEET

University of Canterbury

Department of Communication Disorders



PROJECT INFORMATION SHEET- TEACHER

FOR THE RESEARCH STUDY

Personal FM Systems in Children with Auditory Processing Disorder as
Determined by the LiSN-S Test

TEACHER INFORMATION

You are invited to participate in the research project *Personal FM Systems in Children with Auditory Processing Disorder as Determined by the LiSN-S Test*.

AIM OF PROJECT

The aim of this project is to determine the effectiveness of ear level FM devices as an intervention for students with auditory processing disorder (APD), specifically those who have difficulties with spatial segregation (i.e. ability to separate sounds coming from different directions).

PROCEDURES

Your participation in this project involves a number of tasks, which are outlined as follows:

A. Pre-fitting assessment

Time required: 1 ½ - 2 hours

- Case History

Time required: 5-10 minutes

Information regarding your student's academic history will be obtained. The parents and teachers will be the primary source for this information.

- Children's Auditory Processing Performance Scale (C.H.A.P.S.)

Time required: 10 -15 minutes

The C.H.A.P.S. (Smoski et al, 1998) is a questionnaire designed to assess the observed behaviours of children age 7 years or older. It consists of 36 questions, which examines the child's auditory memory and auditory attention span, as well as their ability to listen in an environment that is noisy, quiet, ideal or in the presence of multiple inputs (e.g. auditory and visual or tactile etc.). Each question consists of a rating

scale from +1 (i.e. less difficulty) to -5 (i.e. cannot function at all). A raw score for each condition is obtained and averaged and compared to available normative data.

- Trial Questionnaire

Time required: 10 - 15 minutes

You will be asked to complete this questionnaire, which is based on the Ministry of Education Questionnaire will. It requires you to evaluate each student's listening skills under various listening environments using a 5-point rating scale.

You will also be asked to comment on the participant's academic performance under reading, writing and maths. Information regarding the ease of operation, troubleshooting and the participant's use of the FM devices will also be gathered.

B. Trial of the FM system

Time required: 8 weeks

You will be given a body worn FM transmitter with a lapel microphone (Phonak Inspiro) for a period of 8 weeks (in line with current Ministry of Education trial for government funded FMs). Your students will also be provided with a pair of ear levels FM receivers. During this trial period, we encourage you to wear the FM transmitter provided throughout the entire school day.

Prior to the trial period, you will have the opportunity to attend an informal workshop held at the Seabrook McKenzie School. You will receive information on the operation and maintenance of the FM system. There will be plenty of hands-on opportunity for you to learn and use the FM system.

During the initial period of the trial, I will be available in person for assistance, should you have any difficulty or concerns regarding the operation of the FM system. All FM devices are strictly for use at school during the trial period.

C. Reassessment

Time required: 1 - 1 ½ hours

At the end of the 8-week trial and again following another 8-week period, you will be asked to reassess your students' listening skills and academic performance using the C.H.A.P.S. and trial questionnaire as described in details above.

Your student's participation in this project involves similar tasks, which are explained in details on a separate form as attached. Test results regarding your student's hearing and reading will be provided to you verbally on the completion of the tests. A comprehensive report outlining the findings of the hearing screening and APD testing will be provided to you on your request.

ELIGIBILITY FOR THE PROJECT

In order for your student to participate in this project, they must meet ALL of the following criteria:

- He/she must be between the age of 7 to 11 years;
- He/she must speak English as their first language;
- He/she must have hearing better than a *Pure Tone Average (PTA) of 20 dB at 500, 1000, 2000 and 4000 Hz; and
- His/her spatial advantage score on the LiSN-S test is outside normal limits of their age group (i.e. they show evidence of spatial streaming segregation difficulties).

*Should a hearing loss is detected, your student will be referred to the University of Canterbury Speech & Hearing clinic for a full diagnostic audiological assessment.

POSSIBLE RISKS

As with the use of any new technology, it is possible that you and your students will experience some stress. In order to minimize this, you will be provided with the opportunity to learn and experiment with the FM system prior to the commencement of the trial period. I will also be available in person and via phone/email to assist you with troubleshooting and ensure the trial is running smoothly.

Similarly, it is possible that your students will experience some stress and fatigue as one would anticipate with any testing that requires attentiveness. In order to minimize this, your students will be given regular breaks between tasks to rest and refresh. Throughout the testing, your students will receive encouragement and he/she will be provided with a small reward upon the completion of testing. You may also wish to be present during the testing to provide your students with emotional support and encouragement. Testing will be discontinued, should you or your students feel distressed at any time.

WITHDRAWAL & CONFIDENTIALITY

Data and results obtained in this study will be made available to Phonak, the company that will be providing the FM systems for use in this study. ***All identifying information and personal details will be removed from this data before it becomes available to Phonak.***

You have the right to withdraw from the project at any time, including withdrawal of any information provided, without prejudice against further care that you may receive at this institution.

The results of the project may be published, but you are assured of the complete confidentiality of data gathered in this investigation. Your identity will not be made public without your consent.

In order to ensure confidentiality, the information gathered will be assigned a code number and all identifiable information removed. Data will be kept in a locked filing cabinet within a lockable room in the Department of Communication Disorders.

The project is being carried out as a requirement for a Masters of Audiology by Fiona Yip, under the supervision of Dr. Natalie Rickard, who can be contacted at the University of Canterbury on +64 3 364 2987 ext. 3052. We will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed ***and approved*** by the University of Canterbury Human Ethics Committee.

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Tasks for Student Participants

Your students' participation in this project involves a number of tasks, which are outlined as follows:

A. Pre-fitting assessment

Time required: 1 ½ - 2 hours

- Case History

Time required: 5-10 minutes

Information regarding your student's birth, developmental, medical, audiological and academic history will be obtained. The parents and teachers will be the primary source for this information.

- Hearing Screening

Time required: 10 - 20 minutes

Your student's hearing will be assessed in a quiet room at the school. Specifically, an *otoscopy* will be performed to visually examine the health of your student's ear canals and ear drums.

Pure tone audiometry will be performed to assess your student's hearing sensitivity. Specifically, his/her hearing will be screened down to 15 dB HL across the important speech frequencies. Various tones will be presented via insert earphones or supraaural head phones. He/she will be asked to press a button each time they hear the tone to indicate they have heard the sound.

- APD Testing

Time required: 45 minutes

Your student's ability to understand speech in the presence of competing speech using the Listen in Noise – Sentences (LiSN-S) Test. Your student will be asked to repeat a target sentence in the presence of noise presented via a pair of specialized circumaural headphones. A speech reception threshold (SRT) will be obtained under each of the four conditions.

- Neale Analysis of Reading Ability Test

Time required: 20 - 45 minutes

Your student will be instructed to read aloud a number of short stories of increasing length and difficulty. They will be timed and a score will be calculated according to the accuracy of their reading.

B. Trial of the FM system

Time required: 8 weeks

Your student will be fitted with a pair of personal FM devices for a period of 8 weeks (in line with current Ministry of Education trial for government funded FMs), while the teacher wears the transmitter all day in one classroom. During this trial period, your student will be encouraged to wear the FM devices provided throughout the entire school day. All FM devices are strictly for use at school during the trial period.

C. Reassessment

Time required: 1 - 1 ½ hours

At the end of the 8-week trial and again following another 8-week period, your student will be reassessed using the Neale analysis of reading ability test as described in details above.

Test results will be provided verbally on the completion of the tests. A comprehensive report outlining the findings of the hearing screening and APD testing will be provided to you and/or your student's parents.

ELIGIBILITY FOR THE PROJECT

In order for your student to participate in this project, they must meet ALL of the following criteria:

- He/she must be between the age of 7 to 11 years;
- He/she must speak English as their first language;
- He/she must have hearing better than a *Pure Tone Average (PTA) of 20 dB at 500, 1000, 2000 and 4000 Hz; and
- His/her spatial advantage score on the LiSN-S test is outside normal limits of their age group (i.e. they show evidence of spatial streaming segregation difficulties).

*Should a hearing loss is detected, your student will be referred to the University of Canterbury Speech & Hearing clinic for a full diagnostic audiological assessment.

POSSIBLE RISKS

As with any testing that requires attentiveness, it is possible that your student will experience some stress and fatigue. In order to minimize this, your student will be given regular breaks between tasks to rest and refresh. Throughout the testing, your student will receive encouragement and he/she will be provided with a small reward upon the completion of testing. You may also wish to be present during the testing to provide your student with emotional support and encouragement. Testing will be discontinued, should your student or their parent(s) feels distressed at any time.

WITHDRAWAL & CONFIDENTIALITY

Data and results obtained in this study will be made available to Phonak, the company that will be providing the FM systems for use in this study. ***All identifying information and personal details will be removed from this data before it becomes available to Phonak.***

You have the right to withdraw from the project at any time, including withdrawal of any information provided, without prejudice against further care that you may receive at this institution.

The results of the project may be published, but you are assured of the complete confidentiality of data gathered in this investigation. Your identity will not be made public without your consent.

In order to ensure confidentiality, the information gathered will be assigned a code number and all identifiable information removed. Data will be kept in a locked filing cabinet within a lockable room in the Department of Communication Disorders, University of Canterbury.

The project is being carried out as a requirement for a Masters of Audiology by Fiona Yip, under the supervision of Dr. Natalie Rickard, who can be contacted at the University of Canterbury on +64 3 364 2987 ext. 3052. We will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed **and approved** by the University of Canterbury Human Ethics Committee.

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APPENDIX 5 – PARTICIPANT INFORMATION SHEET

University of Canterbury**Department of Communication Disorders****PROJECT INFORMATION SHEET- PARTICIPANT**

FOR THE RESEARCH STUDY

Personal FM Systems in Children with Auditory Processing Disorder as Determined by the LiSN-S Test

You are invited to help with a project, which is called *Personal FM Systems in Children with Auditory Processing Disorder as Determined by the LiSN-S Test*.

WHAT IS THIS PROJECT ABOUT?

The classroom is a noisy place! Some children find it hard to hear what their teacher is saying in the presence of background noise. The aim of this project is to examine the use of an assistive listening device (FM System), similar to a walkie-talkie, by children with hearing difficulties in the classroom and to determine if these devices assist the children in hearing their teacher better.

WHAT DO I NEED TO DO?

You will be asked to do a number of listening activities. You will hear either beeps, sounds or words via special headphones, depending on the activity that you are involved in. You will also be asked to either repeat what you have heard or push a button so that we know that you have heard the sound. Sometimes you won't need to do anything other than sitting as quietly and as still as you can!

You will also be asked to do all sorts of reading activities. You will read some short stories and answer questions about them, and you will be asked to read some made up words.

Before each new activity we will explain to you how it works. You can also ask questions and you get time to practise. The listening and reading activities are not difficult – all you need to do is to listen or read carefully.

After all the listening and reading activities, you may be given a pair of assistive the listening devices (like the one in the picture below) that you have to wear EVERYDAY in class for ONE

school term. It is a bit like a walkie-talkie! You will be able to hear your teacher, who will speak into a microphone that she wears around her neck.

You will need to look after these listening devices by making sure they have batteries in them, keeping them clean and putting them back to its case before you leave school to go home every day. It is easy and e will help you with this! So no need to stress!



Will my parents/whanau be there with me?

If you want, you can ask your parent/whanau to be with you.

Where do I have to go?

All the listening and reading activities will be carried out in a quiet room at your school. If you are given a pair of assistive listening devices, you will use them at school only. These devices will be kept at school in a safe place.

On special occasions, we might need to use special equipments that are located in the hearing clinic at the University. In that case, your parents will take you to the hearing clinic, where you will be seated in a comfortable room that is especially designed for testing someone's hearing. It is called a sound treated room.

How long does it take?

It will take about 1 to 2 hours but you will have some breaks.

At the end you will be given a small gift because we would like to thank you for helping us 😊.

APPENDIX 6 – PARENT CONSENT FORM

University of Canterbury

Department of Communication Disorders



Consent Form

Personal FM Systems in Children with Auditory Processing Disorder as
Determined by the LiSN-S Test**Research Student:** Fiona Yip**Supervisor:** Dr. Natalie Rickard

My child has been asked to participate in a research study to determine the effectiveness of ear level FM devices as an intervention for students with auditory processing disorder (APD), specifically those who have difficulties with spatial segregation (i.e. ability to separate sounds coming from different directions).

I have been provided with an information sheet outlining the details of the above named project, and the requirements of my child in this research study. I have read, and understood the requirements as described on the information sheet for the above-named project.

On this basis, I provide consent for my child to participate in this research project. I provide consent for the results of this research study to be published or presented publicly, provided my child's identity is kept confidential and anonymity is preserved.

I understand that my child is free to discontinue participation in this project, and I am free to withdraw my consent at any time, without prejudice against further care that they may receive at this institution. This includes the withdrawal of any information my child or myself have supplied.

NAME OF PARENT: _____

NAME OF CHILD: _____

SIGNATURE OF PARENT: _____

DATED: _____

APPENDIX 7 – TEACHER CONSENT FORM

University of Canterbury**Department of Communication Disorders****Consent Form - Teacher****Personal FM Systems in Children with Auditory Processing Disorder as
Determined by the LiSN-S Test****Research Student:** Fiona Yip**Supervisor:** Dr. Natalie Rickard

I have been asked to participate in a research study to determine the effectiveness of ear level FM devices as an intervention for students with auditory processing disorder (APD), specifically those who have difficulties with spatial segregation (i.e. ability to separate sounds coming from different directions).

I have been provided with an information sheet outlining the details of the above named project, and the requirements of my students in this research study. I have read, and understood the requirements as described on the information sheet for the above-named project.

On this basis, I provide consent to participate in this research project. I provide consent for the results of this research study to be published or presented publicly, provided my identity is kept confidential is preserved.

I understand that I am free to discontinue participation in this project, and I am free to withdraw my consent at any time, without prejudice against further care that I may receive at this institution. This includes the withdrawal of any information I have supplied. I understand that the data obtained in this study will be made available to Phonak, and that all identifying information and personal details will be removed from this data before it will be made available to Phonak.

NAME: _____

SIGNATURE: _____

DATED: _____

APPENDIX 8 – PARTICIPANT CONSENT FORM

University of Canterbury**Department of Communication Disorders****Consent Form****Personal FM Systems in Children with Auditory Processing Disorder as
Determined by the LiSN-S Test****Research Student:** Fiona Yip**Supervisor:** Dr. Natalie Rickard

I have been asked to help in a project to help identify the usefulness of a device on a learning problem. My parents have told me about the project. I understand how I will be helping. I would like to help with this project. If I do not want to help with the project at any stage, I understand I can stop helping with the project.

I understand that this project might be put in a book for other people to read. I understand that my name will not be in that book. I understand that information about who I am will be kept secret.

NAME: _____

SIGNATURE: _____

NAME OF PARENT *(if applicable)*: _____SIGNATURE OF PARENT ON BEHALF OF CHILD *(if applicable)*: _____

DATE: _____

APPENDIX 9 – PARENT QUESTIONNAIRE



UNIVERSITY OF CANTERBURY
Department of Communication Disorders

Children's Auditory Processing Clinic

Parent Questionnaire

The following information will help us in assessing your child. Please complete as much of this form as you can and bring it with you to your child's appointment. Also bring along any relevant documentation from other health/education professionals.

Child's name and Date of Birth

Name(s) of parent(s) or caregiver(s)

e-mail contact

Primary Concern

What is your main concern, or the main reason for the referral?

Developmental History

Were there any complications during pregnancy, or during/after your child's birth? If so, please describe:

Were there any delays in your child's early development, for example, in obtaining milestones such as learning to walk? If so, please describe:

Are there any delays in your child's speech and language development?

Has your child ever had a speech and language evaluation? If so, please describe the results:

Has your child ever undergone an educational or psychological assessment? If so, please describe the results:

Family History

Does your child have any siblings? If so, please list:

Is there any family history of learning problems, difficulty in school achievement (particularly reading or spelling) or hearing difficulties?

Otological History

Has your child ever had his/her hearing tested? If so, what were the results?

How many ear problems has your child had? Please circle:

None 1-2 3-5 6-10 more than 10

Has your child had an ear problem in the last 6 months?

Yes No

Does your child have any of the following? Please circle:

Frequent runny nose	Y/N
Frequent colds or sinus infection	Y/N
Allergies	Y/N
Ringing or buzzing in the ear	Y/N
Dizziness	Y/N

Has your child ever been seen by an Ear, Nose and Throat (ENT) specialist? If so, where and when?

Other Medical History

Does your child require any medications?

Has your child ever had his or her vision assessed? If so, please describe:

Has your child ever had any serious illnesses or accidents including neurological problems, psychological disorders, head trauma or injury?

Education

What school does your child attend? Please provide the name of your child's teacher and principal:

Do you have any concerns regarding your child's academic progress?

Does your child have reading difficulties? If so, please describe:

Has your child ever received classroom support? If so, please describe:

Listening and Understanding

Do any of the following statements apply to your child?

Sensitive to loud sounds?	Y/N
Difficulty hearing in noisy situations?	Y/N
Confused/upset by noisy places?	Y/N
Often misunderstands words that sound similar?	Y/N
Has trouble locating where sounds are coming from?	Y/N
Frequently asks for repetition or says 'what' often?	Y/N
Frequently says 'I don't get it' or 'I don't understand'?	Y/N
Difficulty understanding people who speak quickly?	Y/N
Difficulty understanding people who have an accent?	Y/N
Responds to questions inappropriately or inconsistently?	Y/N
Difficulty detecting humour or sarcasm in remarks?	Y/N
Talks in a flat or monotone voice when reading?	Y/N
Difficulty using prosodic cues (stress, intonation)?	Y/N
Difficulty following multiple directions or instructions?	Y/N
Trouble understanding nonverbal cues (facial expressions)?	Y/N

Behaviour and Skills

Do any of the following statements apply to your child?

Reverses numbers or letters?	Y/N
Difficulty with writing/holding a pen correctly?	Y/N
Poor musical ability?	Y/N
Poor art skills?	Y/N
Easily distracted by other events occurring in the background?	Y/N
Difficulty paying attention or keeping mind on task/teacher?	Y/N
Difficulty taking notes in class (for older students)?	Y/N
Poor organisational skills?	Y/N

Poor behaviour control?	Y/N
Poor social skills and peer relationships?	Y/N
Poor self-esteem?	Y/N
Problems with space perception/coordination?	Y/N
Tactile sensitivity and related anxiety?	Y/N

Is your child right or left handed?

Right

Left

Is there anything else you would like to mention that you think may be relevant to our assessment of your child?

Thank you for taking the time to complete this questionnaire. We look forward to seeing you and your child at the Children's Auditory Processing Clinic.

APPENDIX 10 – EXAMPLE OF GAS

Student: Participant 3Date: 23.04.2010Teacher(s): Teacher C/Teacher DDuration of Treatment: 8 weeks

Step	Goal 1. Ability to listen in the presence of competing speech (re: participation in group discussions)
+2 <i>Most optimistic outcome</i>	Maintains small group discussions (i.e. up to 3 students) 60 to 70% of time with cues AND when up to 3 other students are talking.
+1	
0 <i>Expected outcome</i>	Maintains small group discussions (i.e. up to 3 students) 50% to 60% of time with cues AND when up to 3 other students are talking.
-1	
-2 <i>Current ability</i>	Maintains one-on-one discussions appropriately 90 to 100% of time when 6+ students are talking. Maintains small group discussions (i.e. up to 3 students) 40 to 50% of time with cues AND when up to 3 other students are talking. Maintains larger group discussions (i.e. 4 to 7 students) for less than 40% of time with cues. Does not follow OR disengages* larger group discussions when 6+ students are also talking.

Comments: * Disengages behaviours include being quiet, looking around, turning body away and lack of eye contacts.

Step	Goal 2. Ability to following verbal instructions
+2 <i>Most optimistic outcome</i>	Independently follows 3-step unfamiliar instructions 41 to 50% of time in quiet OR when 4 or more students are talking OR if other background noise is present.
+1	
0 <i>Expected outcome</i>	Independently follows 3-step unfamiliar instructions 31 to 40% in quiet OR when 4 or more students are talking OR if other background noise is present.
-1	
-2 <i>Current ability</i>	Independently follows 2-step unfamiliar instructions 100% of time in quiet OR when 4 or more students are talking OR if other background noise is present. Independently follows 3-step routine instructions 100% of time in quiet OR when 4 or more students are talking OR if other background noise is present. Independently follows 3-step unfamiliar instructions 21 to 30% of time in quiet OR when 4 or more students are talking OR if other background noise is present. Looks at peers for confirmation of instructions given by the teacher 80 to 90% of time.

Step	Goal 3. Ability to listen for extended durations in quiet environment (i.e. story time)
+2 <i>Most optimistic outcome</i>	Listen actively and follows stories on topics not of interest for 4 to 5 minutes in quiet.
+1	
0 <i>Expected outcome</i>	Listen actively and follows stories on topics not of interest for 2 to 3 minutes in quiet.
-1	
-2 <i>Current ability</i>	Listen actively and follows stories for 8 to 10 minutes in quiet conditions AND participates and contributes to discussions/responds to questions 100% of time only when prompted in quiet conditions. Does not engage in stories on topics not of interest in quiet.

Step	Goal 4. Ability to listen in the presence of background noise (i.e. extraneous sources such as traffic)
+2 <i>Most optimistic outcome</i>	Locates teacher visually 60% of time when background noise is present AND asks for /looks at peers for *confirmation.
+1	
0 <i>Expected outcome</i>	Locates teacher visually 60% of time when background noise is present AND asks for /looks at peers for *confirmation.
-1	
-2 <i>Current ability</i>	Locates teacher visually when the teacher is talking across the other side of the room, facing the child's back in quiet conditions 90% of time. Locates teacher visually 50% of time when background noise is present AND asks for /looks at peers for *confirmation.

Comments: * Confirmation refers to looking around to peers to see what it was he was instructed to do by observing and copying their behaviour.

APPENDIX 11 – POST-TRIAL QUESTIONNAIRE (PARTICIPANT)

University of Canterbury

Department of Communication Disorders



POST-TRIAL QUESTIONNAIRE - PARTICIPANT

FOR THE RESEARCH STUDY

Personal FM Systems in Children with Auditory Processing Disorder as Determined by the LiSN-S Test

WOW! Congratulations! You have successfully completed the 8-week FM trial! Thank you very much for your help with this project so far and we hope you have enjoyed the experience😊. Speaking of experience, it is time for some feedback from you! Please answer the following questions by putting a circle around the face that best describes your experience with the FM devices.

1. Putting the devices on my ears was...



Very Easy



Easy



OK



Tricky



Very Tricky

2. When I was wearing the FM devices, I found them...



Very Comfortable



Comfortable



OK



Uncomfortable



Very Uncomfortable

3. When I was wearing the FM devices and the classroom was quiet, I can hear the teacher... than when I was not wearing the FM devices.



Much Better



Better



No Different



Worse



Much Worse

4. When I was wearing the FM devices and other students were making noise, I can hear the teacher... than when I was not wearing the FM devices.



Much Better



Better



No Different



Worse



Much Worse

5. When I was wearing the FM devices and the teacher is talking while moving around the class, I can hear her... than when I was not wearing the FM devices.



Much Better



Better



No Different



Worse



Much Worse

6. During story time while I am wearing the FM devices, I can hear the teacher... than when I was not wearing the FM devices.



Much Better



Better



No Different



Worse



Much Worse

7. Overall, I think the FM devices were...



Very Helpful



Helpful



OK



Unhelpful



Very Unhelpful

8. What I liked about the FM devices...











9. What I disliked about the FM devices...











APPENDIX 12 – AVERAGED PERFORMANCE ON THE CTOPP (FM GROUP)

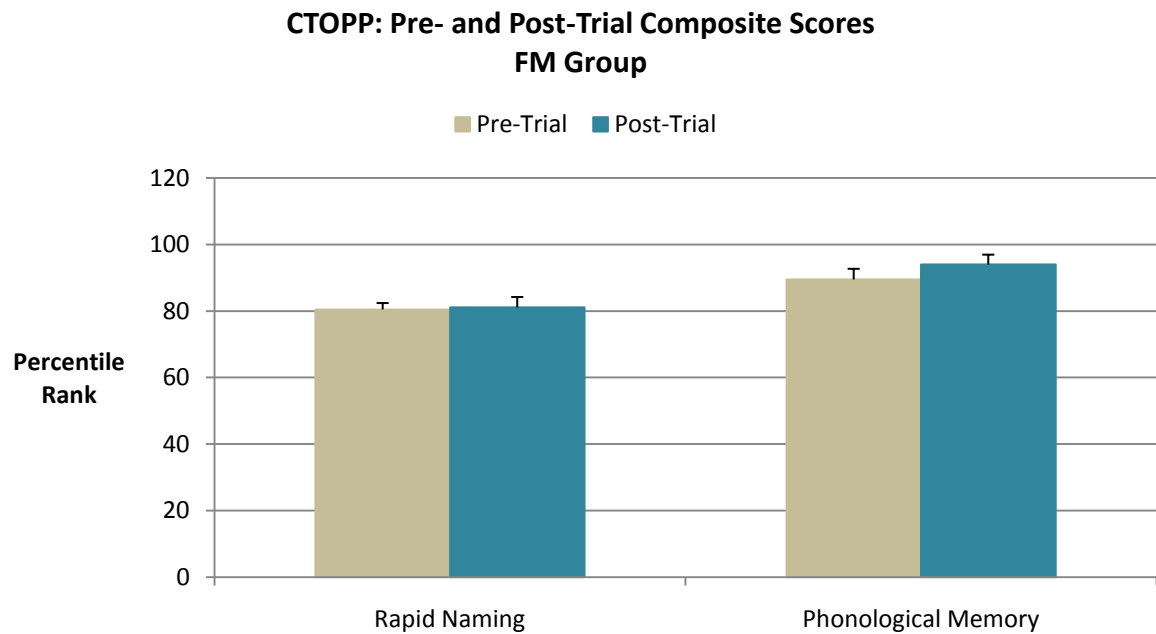


Figure 32. Comparisons between the means and standard errors of means of the FM participants' (n=10) pre- and post-trial composite scores from CTOPP.

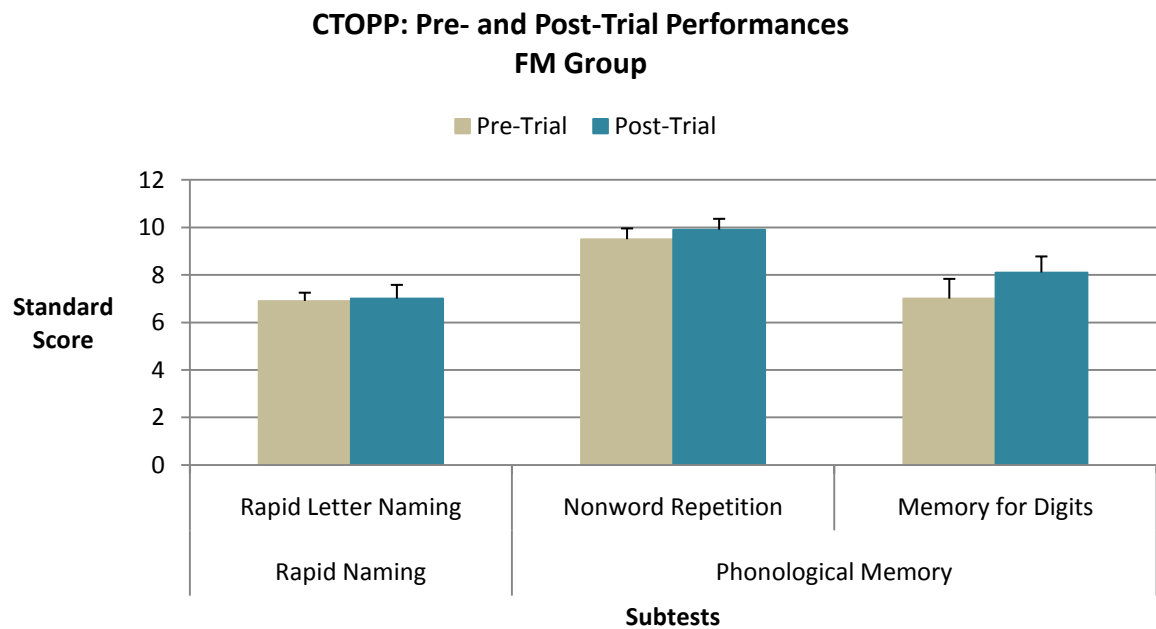


Figure 33. Comparisons between the means and standard errors of the means (SEMs) of the FM participants' (n=10) pre- and post-trial performances for three subtests from CTOPP.

APPENDIX 13 – AVERAGED TEACHER RATINGS ON THE C.H.A.P.S.

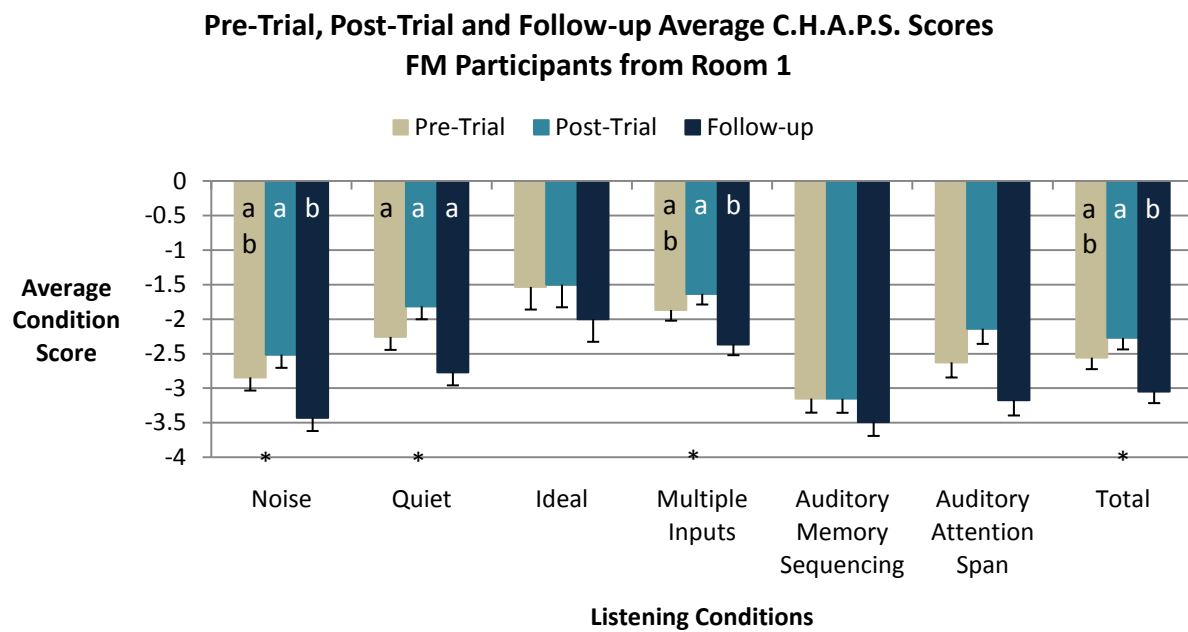


Figure 34. Comparisons between the means and standard errors of the average C.H.A.P.S. scores for the six listening conditions, across the three sampling points for the FM participants from Room 1 (n=5). Results were based on the means of the average C.H.A.P.S. scores obtained from Teacher A and Teacher B. (Means that differ significantly are labelled with different letters; * Significant at 0.05 level).

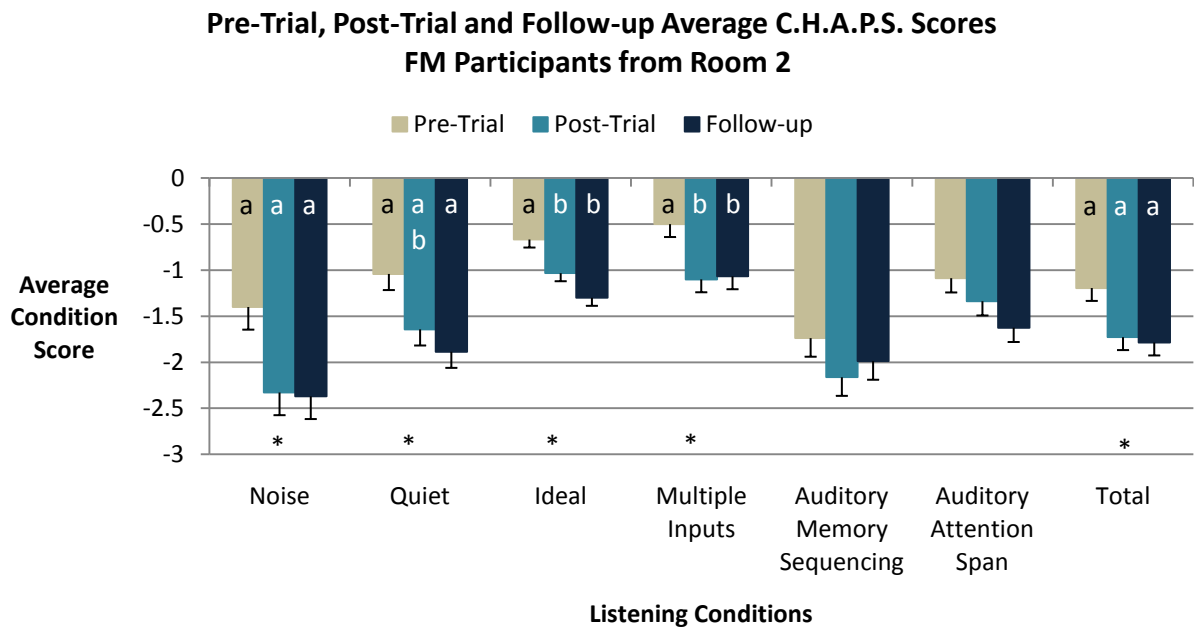


Figure 35. Comparisons between the means and standard errors of the average C.H.A.P.S. scores for the six listening conditions from C.H.A.P.S. across the three sampling points for the FM participants from Room 2 (n=5). Results were based on the means of the average C.H.A.P.S. scores obtained from Teacher C and Teacher D (Means that differ significantly are labelled with different letters; * Significant at 0.05 level).

APPENDIX 14 – GAS T-SCORES

Table 13. Formulas developed by Kiresuk et al. (1994) for the calculation of GAS T-scores.

Formulas for converting summary GAS score into T-score

Equation One:

$$T = 50 \times \frac{10 \sum \omega_i x_i}{\sqrt{(1 - P) \sum \omega_i^2 + P(\sum \omega_i)^2}}$$

Where : x_i represents the attainment score (from +2 to -2);
 ω_i represents the weighting* for a particular goal (i.e. the i th goal)
 P value, set at 0.30, represents the weighted average inter-correlation of the attainment scores (Kiresuk & Sherman, 1968).

This formula produces a mean of 50 and standard deviation of 10.

Equation Two:

The following equation is equivalent to equation one when multiple goals are equally important, as in the case in the present study, where ω_i equals 1.

$$T = 50 + C(x_i)$$

Where the value of C (i.e. a constant) changes according to the number of GAS scales that is evaluated at the end of the intervention period. Specifically, the value of C is 3.63 when a total of 4 GAS scales, as in this study, are evaluated at the end of the intervention period.

*Weight = importance x difficulty

Where:	<i>Importance</i>	<i>Difficulty</i>
	0 = not at all	0 = not at all
	1 = a little	1 = a little
	2 = moderately	2 = moderately
	3 = very	3 = very

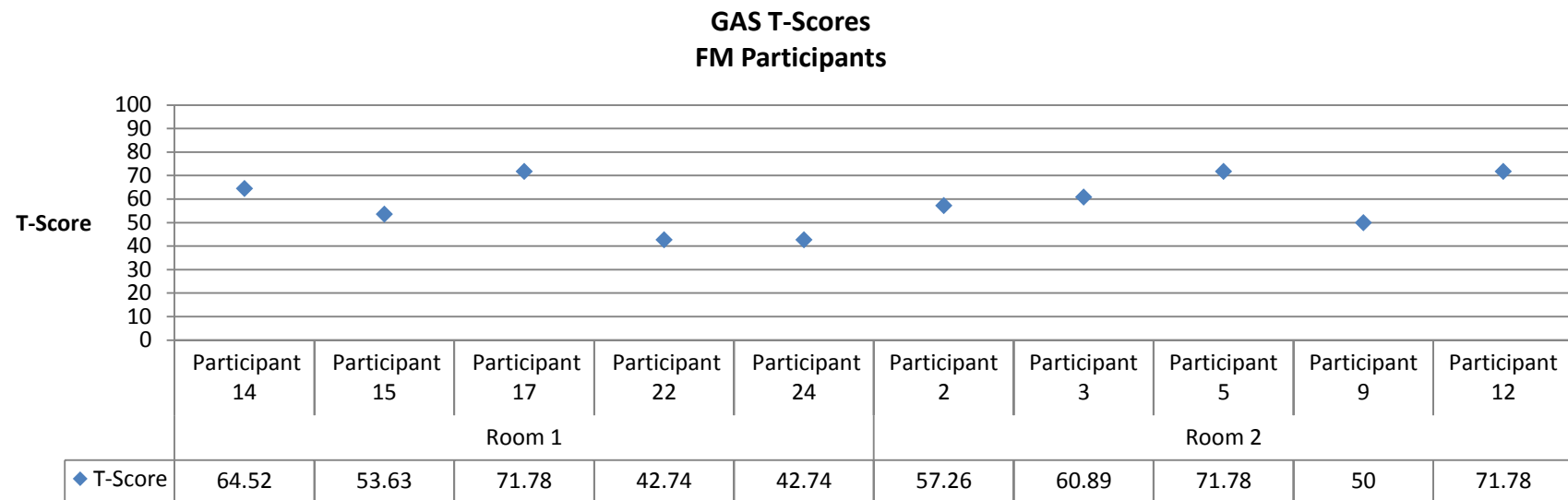


Figure 36. Individual GAS T-scores for the FM group (n=10).

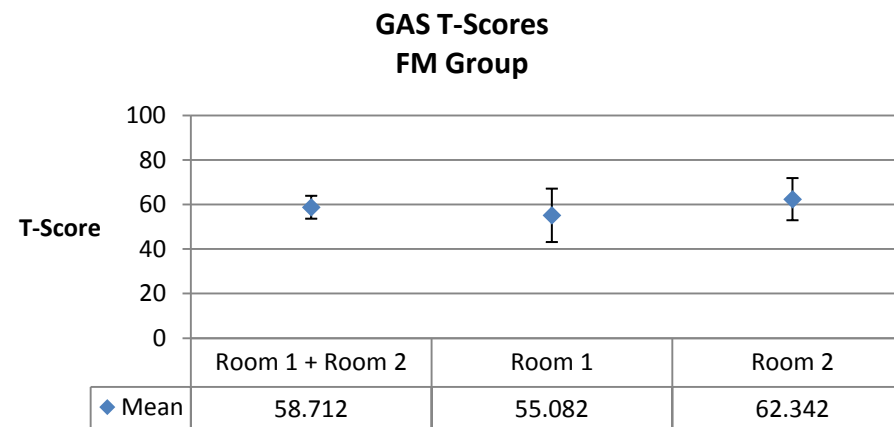


Figure 37. Mean and standard errors of the GAS T-Scores for FM participants from Room 1, Room 2 and both classes combined.